The Journal of the

INSTITUTION OF PRODUCTION ENGINEERS

VOL. X SESSION 1930-31 No. 10

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"*. . . . . . . the keen*
Unpassioned beauty of a great machine"
—Rupert Brooke.

HYDRAULIC TRANSMISSION AND MACHINE TOOLS.

Paper presented to the Institution, Manchester and Coventry Sections, by T. E. Beacham, A.M., Inst.C.E., and J. Robson, M.I.Mech.E.

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THE special advantages of hydraulic transmission of power have long been recognised by engineers. Central pumping stations provided with hydraulic accumulators distributing liquid under pressure through pipes have been widely employed in workshops for many years, and the hydraulic power applied to presses, riveting machines and other tools where great force was necessary. It is only in quite recent years that self-contained hydraulic transmissions have been applied to a large variety of tools, and as many members of this Society may not be familiar with recent advances in hydraulic transmission, a description of the modern hydraulic variable gear in which oil instead of water is employed, may be of interest.

The type of hydraulic system which forms the subject of this paper differs from the old system of distributing pressure water in that each machine requiring hydraulic operation is provided with its own little pumping plant, and as a rule an accumulator is dispensed with. This not only eliminates most of the waste of power unavoidable in distributing hydraulic power from a central station, but also enables fairly viscous lubricating oil to be used instead of water, and the pumping plant, now that lubricating oil is the medium, can be of the rotary type of machine in which both valves and soft packing to retain the pressure are dispensed with, giving great advantages over the orthodox hydraulic pump in the matter of cheapness of construction, besides eliminating wear and corrosion.

Possibly the earliest and simplest of such self-contained hydraulic transmissions is shown in Fig. 1, and consists of a double acting ram or piston, the hydraulic pressure being provided by an ordinary gear pump, which pumps out of the reservoir *B* into the pressure pipe *P* to the reversing valve *V*, which controls the distribution of the pressure to the two ends of the hydraulic cylinder. It will be seen that if the valve *V* is moved upwards, that pressure is admitted into the right-hand end of the cylinder and that the piston will move left, on the other hand if the valve *V* is moved downwards, pressure is admitted into the left-hand end and the

Manchester, February 9th ; Coventry, March 4th.

piston will move to the right. In the centre position, the valve shuts off both passages to the cylinder and the hydraulic pressure having no other escape blows past the safety valve *S*, and returns to the reservoir. Such a transmission will give a perfect control over the motion of the piston, as the valve may be partially shut and the speed reduced to any desired amount by throttling the flow. This type of gear has been used for many years as a servo-motion for the operation of the governors of water turbines, and it also forms the basis of many machine tool feeds.

Its employment is restricted to low powers, because the use of gear pump is limited to comparatively low pressures firstly because of internal leakage. It will be seen by referring to Fig. 1 that there

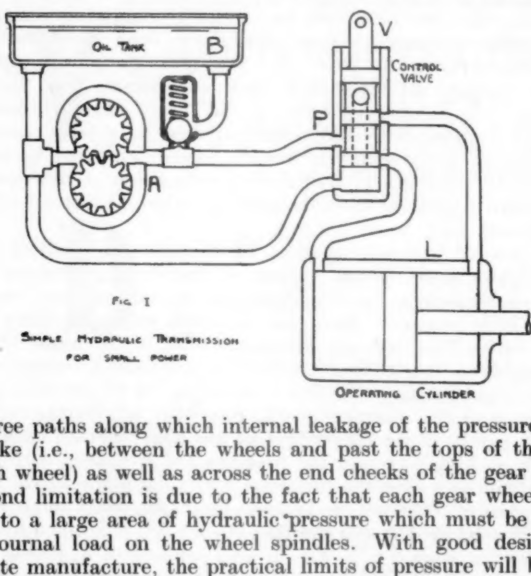


Fig. I

Simple Hydraulic Transmission for Small Power

are three paths along which internal leakage of the pressure liquid can take (i.e., between the wheels and past the tops of the teeth of each wheel) as well as across the end cheeks of the gear wheels. A second limitation is due to the fact that each gear wheel is exposed to a large area of hydraulic pressure which must be carried as a journal load on the wheel spindles. With good design and accurate manufacture, the practical limits of pressure will be from 100 to 150 lbs. per square inch. With such a limitation any hydraulic piston to exert substantial force must be unduly large, and as the pump delivery is from 12 to 15 gallons per minute per h.p. transmitted, large size pipes and control valves are required to avoid undue losses.

The second limitation of the gear pump is due to the fact that its capacity is fixed. No matter what the demand is, the pump delivers the same number of gallons per minute, any surplus passing through the safety valve and especially in the case of control and

feed gears, there will be many occasions where the whole delivery is wasted in this way for long periods unless special valves are provided to bye-pass oil when not required. Discharging through safety valves not only involves waste of power, but such waste power is dissipated in heat, the oil as its temperature rises loses its viscosity and in consequence the internal leakage of the pump increases to a point at which it will no longer maintain the pressure. A concrete instance will illustrate the point. If the transmission is to exert a maximum of one h.p. and contains five gallons of oil in circulation, while no pressure oil is being usefully employed, all the power is converted into heat and one h.p. is equivalent to approximately 2,500 B.Th.U's. of heat per hour and, assuming that the pump, connecting pipes and tanks have a total weight of say 50 lbs. of iron of which the specific heat is .13, then :

Water equivalent of oil ...	...	$= 5 \times 9.5 \times 0.5 =$	23.75 lbs.
,, ,, metal	...	$= 50 \times .13 =$	6.5 ,,
		Total ...	30.25 lbs.

and the temperature rise apart from radiation losses will be approximately 80° F. per hour.

These two difficulties are completely overcome by the use of a variable stroke high pressure pump. Although vane pumps have been used for this purpose (chiefly in Germany by Lenz, Pitler, and others) such pumps have as a general rule employed cylindrical pistons which can be made to fit so accurately that pressures of 1,000 and even 2,000 lbs. per square inch can be used without appreciable internal leakage. The model on the table illustrates what can be accomplished by means of cylindrical pistons having no rings or packing of any description. The pistons in this little pump are no more than an eighth of an inch in diameter, and yet it will be seen that the pump will easily give 3,000 lbs. per square inch. With most of the V.S. pumps now in common use, any delivery from zero to a maximum in either direction can be obtained by varying the stroke of the plungers, and in consequence it is no longer necessary to pass any excess delivery through a safety valve and so cause undue heating and loss of viscosity.

One of the earliest variable stroke pumps was due to Hall, who as long ago as 1905 made a hydraulic transmission consisting of a variable stroke pump and fixed stroke hydraulic motor which was used to operate a petrol lorry running in London. Although the gear functioned well it did not attain commercial success. (A very complete description of this gear was given in the *Commercial Motor* of January 17th, 1907). The first variable stroke pumps to

be widely used were probably those due to Dr. Hele-Shaw in this country, and Messrs. Williams & Janney in America, the first perhaps being best known in connection with ships' steering gears and the second in connection with the operation of gun mountings, though both have been employed for a large number of naval, military and industrial purposes, and built in sizes up to 200 h.p. Subsequent to these other types of variable stroke pump have been developed, more especially for industrial purposes, among which may be mentioned that of the Oil Gear Company, of Milwaukee, U.S.A., and the Hele-Shaw Beacham pump by the well-known engineering firm of Messrs. Greenwood & Batley, of Leeds.

We now propose to describe in detail two of these pumps. Firstly the Williams Janney which has axial cylinders operated by a swashplate mechanism. Second, the Hele-Shaw Beacham pump

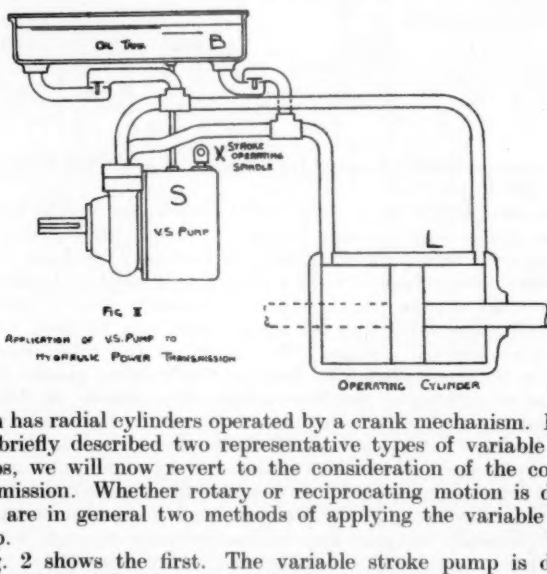


Fig. I

Application of V.S. Pump to Hydraulic Power Transmission

which has radial cylinders operated by a crank mechanism. Having now briefly described two representative types of variable stroke pumps, we will now revert to the consideration of the complete transmission. Whether rotary or reciprocating motion is desired, there are in general two methods of applying the variable stroke pump.

Fig. 2 shows the first. The variable stroke pump is directly connected to a double acting cylinder (or hydraulic motor) which latter is controlled directly by means of the stroke operating spindle of the pump. With this in mid-position no movement of the piston takes place. Pushing in the piston will cause the oil to circulate and the piston to move, say, to the left, while pulling out the stroke shifting spindle will reverse the flow of oil in the pipes and cause the piston to move to the right. In operating, oil continuously

leaks past the pistons and valve of the pump, and this is returned to the system automatically by the non-return valves shown. One of the main pipes will be under pressure and the other under a slight vacuum, on account of oil loss. This vacuum will cause the respective non-return valve to lift and draw in oil from the tank. Safety valves are normally fitted which prevent any accidental damage if the piston is pumped up against the limits of its travel or encounters any abnormal resistance. With the type of hydraulic cylinder shown it will normally be necessary to use a tail rod as shown by the dotted line in order to make the effective area of the piston the same in either direction. However, it is sometimes convenient to employ unequal areas for the purpose of a quick return in which case arrangements must be made to lift one non-return valve when the small side of the piston is under pressure, or a reversing valve may be used as is the case of the broaching machine referred to later.

An alternative method of employing the V.S. pump consists in arranging for the pump to pump against a predetermined pressure, its stroke being controlled automatically by a ram and spring. The spring is arranged to force the control to the maximum stroke position and the ram operated from the pressure is arranged to overcome the spring and reduce the stroke immediately a predetermined pressure is reached. In this system, any number of cylinders or motors, or both, can be operated from one pump. Each has its own reversing valve similar to that previously described in Fig. 1. Although the pump is in this case continuously under pressure, it will be noted that when no pressure oil is being used, none is being pumped and that, therefore, there is no heating due to bye-passing.

Application of Hydraulic Transmission to Machine Tools.

For the main drive. We have seen (see Fig. 2 and description) how a variable stroke pump in combination with either a double acting cylinder or a rotary hydraulic motor can be used as a variable transmission gear for either reciprocating or rotary motion. Such a gear presents a combination of advantages which no other system of power transmission offers. These advantages are as follows: (1) With the pump end rotating at a constant speed the motor (or ram) end can be varied from a maximum to zero and reverse in infinite graduation; (2) this regulation is effected by the motion of a control spindle requiring little effort to operate, and which can be worked either by hand or automatically in various ways to meet any particular requirement; (3) by means of suitable safety valves the gear will stall exactly when a certain predetermined torque or effort is reached, this protects both the gear and the machine from overload and accidental damage; (4) a pressure gauge gives at all times an exact indication of the torque or effort;

(5) the lubrication of the mechanism is as near perfection as possible as oil is continuously being squeezed past the working surfaces by the pressure and the greater the load the higher the pressure and the consequent flow of oil past the pistons, etc.; (6) no piston rings or packings of any description are employed in the internal mechanism and this, combined with the perfect lubrication and freedom from overload practically eliminates wear or maintenance.

For rotary motion efficiency is generally less than with a corresponding arrangement of toothed gears. Test bench efficiencies of hydraulic gears (of the piston type) over 85 per cent. have been measured, and in actual service such gears of moderate size with a torque range up to four to one will give efficiencies over 70 per cent. at full load. While the actual increase of the cost of power on this account will not as a rule be a serious item, if the gears are in continuous operation provision must be made to keep the working temperature to a reasonable limit to avoid unduly reducing the viscosity of the oil. Where the pump and motor unit are separated sufficient surface may often be provided by the connecting pipes to radiate the heat, but where the pump and motor are adjacent water cooling coils may be necessary for this purpose.

For rotary motion where the hydraulic gear is to displace some simple form of toothed gearing the practical limitation to the commercial employment of the gear is that of first cost, and in considering any particular application the advantages of the gear must naturally be carefully weighed against any increase in the capital cost of the machine.

One important matter in this connection must not be lost sight of and that is that the size and characteristics of any variable speed gear are not entirely defined by horse power to be transmitted. What must also be known is the range of output speed over which the full horse power is required, or in other words the torque range. A variable gear for instance, to transmit five h.p. over a speed range of 500-100 r.p.m. must be capable of exerting twice the maximum torque of a gear to exert the same horse power over a range of 500-200 r.p.m., and will in general require cylinders of twice the cubic capacity.

A variable speed gear suitable for a lathe headstock and similar purposes requires a particularly large torque range which makes a hydraulic drive for such a purpose very heavy and expensive for the horse power to be transmitted, although the advantages are obvious. It is possible with hydraulic operation to obtain the exact cutting speed required under all conditions and for surfacing operations the r.p.m. of the headstock can be continuously and automatically varied to keep the cutting speed constant. Tests on a lathe fitted with hydraulic drive have indicated an increase in output of 25 per cent, but so far the increase in the capital cost

of the machine has limited the employment of hydraulic drives to exceptional cases. A veneering machine might be mentioned. In this machine the sheet of veneer is slit from a cylinder of wood, and the headstock requires to be speeded up continuously as the cylinder is reduced in diameter; hydraulic gears have been used with great success for this purpose. There is no doubt that when and if hydraulic gears are available at cheaper prices their use for headstock drives will be widely extended.

In machine tools where the main drive is employed to effect reciprocating motion conditions are very different from those for rotary motion and more favourable to the employment of hydraulic operation. In the first place the combined efficiency of a variable stroke and a ram is often much greater than the mechanical arrangements usually employed to effect reciprocating motion and, in the second place, the hydraulic transmission for reciprocating motion is cheaper than for rotary motion, whereas for mechanical transmissions the reverse is the case. There are, therefore, many machines in which all the advantages of hydraulic transmission can be obtained with very little or no increase in the capital cost.

There are many types of presses for various workshop operations which in the past have been operated by steam and water pressure, which without doubt lend themselves to more economical operation by means of variable stroke pumps adjacent to the press and driven either by belt or electric motor. The photographs show a number of such presses. On the other hand there are also many types of workshop presses which in the past have been driven by purely mechanical power, for which the new transmission would provide all the advantages of hydraulic working without entailing the cost and up-keep which have been drawbacks in the past.

A similar application of variable stroke pumps is for the operation of the hydraulic cylinder in a testing machine which applies the pressure and takes up the stretch of the specimen, and the use of a V.S. pump for this purpose is now standard practice. A special type of testing machine is the spring scragging machine; in which a vertical double acting ram is driven and controlled by a V.S. pump. This machine is used for the routine testing of large springs by compressing them quickly a number of times.

Hydraulically operated broaching machines have been developed in America and widely used. Here the screw of the mechanically operated broach has been replaced by a double acting piston, operated from a V.S. pump. The speed can be exactly adjusted to give the best possible finish, and the oil pressure required to pull the broach gives an indication as to whether the broach requires regrinding. The provision of a safety valve prevents breakage of broaches. Vertical as well as horizontal machines are made on this principle.

Several hydraulically operated planing machines have been produced. One of the first was constructed by the Coventry Ordnance Company some twenty years ago. In this machine a Hele-Shaw pump was used to operate the table by means of rams. Similar machines were in use for a number of years in the workshops of Messrs. Hydraulic Gears, Ltd. In a recent number of *Machinery* two German hydraulic planing machines have been described. The development of the hydraulic planer has probably been slow on account of several all-electric planer drives which reached an advanced state of development before any hydraulic scheme appeared. The shaping machine also offers possibilities for hydraulic operation, as the tool could be reciprocated by a cylinder arranged so as to give a more uniform cutting speed than is possible with a mechanical drive.

Application of Hydraulic Transmission to Machine Tool Feeds.

There has, undoubtedly, been a rapid development within the last two or three years in the employment of hydraulic drives for the feed movements of machine tools. The simple hydraulic arrangement of Fig. 1 shows all the essential parts of a variable speed and reversing traverse which has been employed for a number of different purposes, and which is vastly more simple than any possible mechanical equivalent.

Its advantages over mechanical feed are (1) it provides not only infinite variation of speed but also immediate control of the speed. It provides in itself a rapid traverse to the commencement of the cut, and also the possibility of varying the speed during the cut when necessary ; (2) it gives a steady cushioned motion eliminating possibility of any jerkiness or irregularities such as may be introduced into a mechanical drive by the imperfections of gear wheels, screw threads, universal joints, etc. ; (3) the oil in the cylinder is not rigid but provides an elastic cushion as mentioned above, which enables the tool or grinding wheel to start a cut with less shock than is the case with the more rigid mechanical feed, and in consequence there is less irregularity at the commencement and finish of the cut.

What a hydraulic feed will do is to provide an exact and definite velocity ratio such as is required for screw-cutting. We have previously seen that there are limits to the power for which the simple arrangement in Fig. 1 can be employed due to the low pressure of the gear pump and the generation of heat.

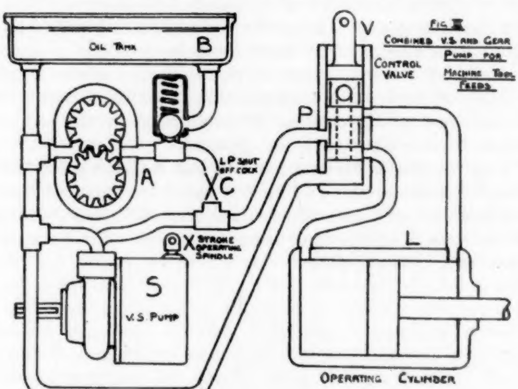
In connection with machine tool feeds there is a further item which must be considered and that is the speed regulation by means of the valve. The speed regulation with this arrangement is obtained entirely by throttling through the valve, and the speed of the feed

will depend on the resistance to the movement. Suppose, for instance, the oil pressure is 100 lbs. per square inch and the valve is set to obtain the required feed, and the pressure in the cylinder is 50 lbs. per square inch. The remaining 50 lbs. per square inch are destroyed by throttling through the valve. If now the cut is increased so that the ram pressure becomes 75 lbs. per square inch the pressure lost in throttling will decrease to 25 lbs. per square inch, and the speed of the feed will diminish by some 30 per cent. If on the other hand, the cut is taken off altogether, so that the ram pressure becomes zero, the pressure lost in throttling will be 100 lbs. per square inch, and the speed of the feed will increase some 50 per cent.

Thus for the same setting of the valve there may be a wide difference of speed for different resistances, that is to say, each setting will give a higher speed for a light cut than for a heavy cut, which may or may not be an advantage for the particular purpose required.

Another condition affecting the speed will be the viscosity of the oil. The oil will heat up during running and become thinner and flow through the valve more easily. Thus the tendency will be to get lower speed feeds when the machine is started and increasing speeds until the oil reaches its normal temperature.

Turning now to Fig. 3, which shows a combination of variable stroke pump and gear pump. With this combination the gear



pump provides a large supply of low pressure oil for the rapid traverse, and the variable stroke pump a small supply of high pressure oil for the feed. When feeding against the cut the gear pump is shut off by the cock *C*, and the control valve is wide open

so that no control takes place by throttling, the speed of the feed being regulated entirely by the stroke of the V.S. pump by adjusting the spindle. The speed of the feed is now practically independent of the resistance encountered, and the variation between nothing and full load will only be that due to leakage and slip in the pump and ram, which should not be more than a few per cent. Moreover, the motion of the spindle *X* will be directly proportional to the velocity ratio between the revolutions of the pump, and the feed speed, and can be accurately indexed.

Fig. 3 is, of course, only diagrammatic and intended to illustrate the principle involved. Many modifications are desirable in certain instances. For instance, the suction of the V.S. pump can be taken from the pressure side of the gear pump, in which cases for low pressure work the V.S. pump becomes only a metering pump and extreme accuracy of speed setting is possible. The control valve *V* and shut-off valve *C* can be combined and their control interconnected with the stroke varying mechanism, as is done in the case of the oil gear pump.

The authors have collected together a number of photographs and illustrations showing various types of lathes, milling machines, drilling and boring machines, band saws, shapers, presses, grinders, etc., which the members may care to examine after the meeting. The authors wish to point out that they undertook with a good deal of diffidence to give this paper before an institution, the members of which have such an intimate knowledge of and connection with machine tools. The authors disclaim any detail knowledge of machine tool design, but they have both spent a considerable part of the last twenty years in developing various applications of the type of hydraulic transmission gear dealt with to-night, which is the excuse they have for venturing on the subject of its application to machine tools in general.

They wish to thank Messrs. Greenwood & Batley for the loan of the variable stroke pump and slides, also the Variable Speed Gear Company for loan of slides illustrating the Williams Janney pump, and the various machine tool manufacturers who have so kindly lent slides and illustrations.

Discussion, Manchester Section.

Mr. Gorst, who presided : I think you will all agree that we have just heard an excellent lecture on a not particularly well-known subject, and one which I am quite sure will be found both useful and instructive to most of our members and visitors. I do not agree with the modest declaration of our friends the lecturers—they have proved themselves to be masters of their subject, and I think that during the evening's proceedings we shall manage to extract from them quite a number of excellent ideas and useful information.

Mr. Chipperfield : I think that, without doubt, we will all agree that the lecturers have laid before us some very interesting particulars of pumps suitable under certain conditions for operating machine tools. The lecturers call their paper "Hydraulic Transmission and Machine Tools." I must say that I feel a little disappointed that they have not given us a few more particulars as to how hydraulic transmission can be applied to machine tools. I appreciate very fully indeed that they are not quite so familiar with machine tools as they are with pumps, and we undoubtedly appreciate that they do know something about pumps. No doubt there are a good many of us who are directly interested in machines who know a lot about machine tools but know nothing about pumps.

Now, in the paper I noticed that there was a rather casual mention of the question of the cushioning effect of hydraulically operated rams. There is no doubt about it that this is a matter calling for very careful consideration. We are led to suppose, or left to believe, shall I say ?—that oil and water are not compressible from the theoretical standpoint. Railway engineers do know that when they are removing the wheels from an axle that the ram will develop pressures from two to three hundred tons without any appreciable movement of the ram. The only conclusion we can come to is that the pressure was exerted and taken up by the elastic stress developed in the construction of the press, and I think that oil and water under atmospheric pressure do compress by a small percentage. However, it is a fact that you cannot get from hydraulically operated rams driven by oil and water a definite fixed motion relative to the pressure that is put in. There is bound to be a cushioning effect, and that cushioning effect is a matter that is calling for very serious attention by the designers of machine tools. A well known maker of machine tools found it necessary to use two pumps, one a constant pump for accelerating the pressure at the forward stroke of the piston or plunger operating the machine tool, and another a variable stroke pump for regulating the exhaust. By that it is obvious, I think, to all of us, that it is brought about by the necessity for taking complete control of the piston operating the machine tool as far as mechanical means will permit. Now,

although the necessity for such a plunger has been taken care of in that respect, we have heard that even under those conditions, the table of a milling machine will go, shall I say, with rhythmic jumps relative to the variation in the thickness of the chip that comes from each blade of the milling cutter. Strange to say, although such an operation may look peculiar, we have heard that under these circumstances the work is performed with a much better finish.

We must approach the hydraulic operation of machine tools with caution. It is a very difficult thing and should be handled with extreme care. At the present time I am interested in the building of a very large lathe. The lathe has a total weight of 170 tons; the bed is about 75 feet long. There are four saddles (two back and two front), and each saddle is fitted with an independent apron. There is geared feed change and six changes of feed. Now looking at the hydraulic operation of machine tools from the standpoint of using a piston and ram so that the oil pressure feed to that piston propels the saddle along the bed, it is obvious that one cannot use a ram of that description on any machine tool of considerable length. The ram must project a considerable distance beyond the total length of the machine. Therefore, we have recourse to the means of using a motor, as our friends have illustrated to us, with a changeable stroke pump and oil. Now when you think of the possibility of a designer having to put on the apron or the saddle of large length a unit mechanism of that description, one begins to wonder whether it is more simple to put a simple apron with change gears in it, and shafting alongside the machine. I mention these matters because, while we appreciate very thoroughly indeed the paper that the authors have brought before us as a means for showing the marked progress in the methods or possibilities of hydraulic transmission, we have got to look upon these matters with a considerable amount of caution, because very few of us in these hard times can afford to throw money away. As far as I am concerned, in the business with which I am connected, nearly every machine tool we make is an order, not an experiment, and so we have to go forward with a considerable amount of caution.

I would just like to say a word in regard to the power for operating headstocks on lathes. One is inclined to think that there is something as far as infinite change of speed is concerned in fitting a hydraulic motor for directly operating the main spindle of a lathe. Machine tool designers have got to be broadminded and accept any suggestions that come their way whereby they can increase the efficiency of machine tools, but I think production engineers are bound to ask as a first question whether the hydraulic operation of machine tools is going to increase the output of the production plant.

MR. STIRK : The application of hydraulic power to machine tools has a certain fascination for me, and whenever I read an article on the application of hydraulic power to machine tools, and whenever I hear of the possibility of a demonstration of such an application, such as at the Leipzig Fair, or a lecture, I always experience a feeling of fear, but after witnessing such a demonstration I feel as if I am reprieved and that I can carry on for a few more years on the same lines that I have pursued hitherto. I have been interested and impressed with the description of the pumps, and equally interested, but not so much impressed, with the description of the application of the system to machine tool work, particularly main drives. An impression I had is pretty well confirmed that there is a very wide field for the possible application of hydraulic transmission to feed motion on certain classes of machine tools, particularly milling machines and grinding machines, but I am, as I have indicated, quite convinced that as an electric and mechanical engineer, I have nothing to fear from the hydraulic engineer. The practical difficulties are tremendous. We received an S.O.S. from one of our continental agents describing two hydraulic machines at the Leipzig Fair which were considered to be very serious competitors to electric reversing motor drive. I went over to meet him and see these tools. The first one did not alarm me at all. It was staggering very badly, even when running light. The other was silent, smooth, prompt on reversal—and I was getting alarmed. I went away with something of a slightly sinking feeling to look at a few other things until I had recovered, and when I went back to have another look at it I felt much more cheerful. Even if, stationed a hundred yards away, I hadn't heard the pump, the only other thing I should have noticed would have been the staggering of the table, which was very obvious indeed. When I went again just to take a last look at it, to my great delight I found that it was completely broken down. There is one thing in the lecture which interested me specially, and that was the reference to the utility of the hydraulic drive for broaching, because to my great amazement, I learned the other day, by accident, of some people on the continent having bought a big planer of ours for plaining slots, and they broached out the dove-tailed portion.

MR. HUTLEY : I am in rather an awkward position, I am afraid, as I am very much in favour of hydraulic transmission. I would say that Mr. Stirk's great fault was in going to see a German machine instead of looking at a British. Mr. Chipperfield has taken a rather exaggerated case, in taking a very long bed. If you want to put the hydraulic drive on a planing machine for a long traverse you are naturally limited when using a ram and cylinder, as their overall length when fully extended is more than twice the working stroke. The question as to whether it is worth while depends

entirely on the duties it has to perform. If you want a big variation, naturally it is going to be well worth while. The noise referred to by Mr. Stirk was probably due to air getting into the hydraulic system when starting up.

MR. FORBES : I would like to ask the authors whether they have had any experience of the actual effect on the finished product in the two following systems—using a gear pump and relief valve with a variable stroke pump, and the use of the open circuit against the closed circuit. The oil pressure chosen for special jobs must be carefully considered, and I should like to ask the authors what they recommend as being the more suitable pressure for machine tools. This will probably show a slight variation due to leakage to obtain a very high finish on the work. One point strikes me in regard to the third diagram on the extreme right. The authors show that the variable stroke has been used and the gear pump must bye-pass all its oil through a relief valve. I should like to say that during the feeding stroke the gear pump of the Greenwood & Batley pumping unit does not bye-pass this oil through a relief valve, but that a special passage in the control valve comes into action, and the gear pump only provides sufficient pressure to flood the suction of the V.S. pump. The heating of the oil through the relief valve which was mentioned by the authors is thus eliminated. In my opinion both electric and hydraulic drives are needed for machine tools. Thus, in a drilling machine the drill should be rotated by a direct electric drive and fed by means of a hydraulic feed. Also, for a honing machine, the hones should be rotated by electric motor and reciprocated up and down in the bore by hydraulic means.

MR. WILCOCK : I would like to ask the lecturers if they have had any experience of hydraulic mechanism for chuck work. It appears to me, on the face of it, that there is quite a big field to be explored in the way of chucking on various machine tools. We have recently installed quite a number of air chucks. Well, no doubt you will appreciate that we have to have one central power station for our air supply, and it has struck me that with such small pumps each machine tool could be equipped with its own power station. I would just like to know whether you have had any experience in that direction. We have had them two years now broaching, hydraulically operated, supplied by the Lapointe people. With the broaches set and the pressure gauge mounted on the machine, the operator can tell at once when his broaches are ready for sharpening.

MR. H. SHAW : I would like to ask the lecturers whether hydraulic feed can be used for screw-cutting. I do not see why we cannot dispense with the change gears on the screw-cutting machine if we drive from a variable high speed hydraulic pump through reduction gears to the lead screw, synchronising this pump with one driving the work. Also, we could change the lead of the screw

at the pump. I believe the variation in the speed of the rotary pump is very little.

MR. F. W. SHAW: I think it is about twenty years ago since I heard of the first application of hydraulic power to machine tools. Some gentleman in Liverpool constructed a turret lathe, perfectly automatic, operated entirely hydraulically, as far as feed motion was concerned. The lathe was driven in the ordinary way and the spindles were driven in the ordinary way, and he operated the valves which cut off and put on the hydraulic power by stops. When one piece had been produced by feeding by hand, the stops were set, after which operation was automatic, by hydraulic motion. The question of compressibility came up and I should like to know what is the co-efficient of compressibility for oils of different viscosity.

MR. LIEBERT: "The proof of the pudding is in the eating" and there is certainly a great demand at the present time for hydraulically controlled machines as regards feed motions. Now, as regards broaching, the Ford company use nothing but hydraulically operated broaching machines, and many of the new machines that are coming over from America have the hydraulic feed for operating chucks. I am sure that there is a very big market.

A VISITOR: I should like to ask this one question. How would the lecturers apply the feed economically to four separate slides on one machine moving 10 to 12 feet? It seems to be hardly economical to do it in this way. I should be obliged for any information on this subject.

MR. BEACHAM: Mr. Chipperfield and Mr. Shaw mentioned the question of compressibility of oil. Well, we were all taught when we were young that oil and water were incompressible. However, practical experience chearly shows that oil is compressible whether you apply it for piston or rotary motion, and it has exactly the same effect as a spring drive; the higher the pressure of drive, the greater the spring. As far as co-efficiency of compressibility is concerned, the figure that I have seen quoted (but I am not sure how accurate it is) is 1/3 per cent. volume for every 1,000 lb. per square inch. While with a rotary hydraulic drive the spring is a constant quantity when using a ram, the farther the ram is out, the more spring you will get. If the stroke is five inches and the pressure 1,000 lbs. per square inch, the total compression would correspond to just over 100th of an inch linear movement of the ram, and there are undoubtedly cases where trouble has occurred due to some chatter in the milling cutter or other spring of the tool getting in tune with the period of springiness of the hydraulic system and you would get a jerky motion. The cure for that is in most cases a reduction of pressure. The system should be properly designed to entirely exclude air. The big jerks about which Mr.

Chipperfield spoke are possibly due to air getting in the system.

With regard to the question of feed on a lathe and a big planing machine, Mr. Hutley has pointed out that the difficulty in both cases is in getting in the long ram. The amount of travel possible with a ram is less than half the total machine length, and if you take a planing machine drive, as a rule I believe the traverse of the machine is more than half the floor space occupied by the machine. One German machine has telescopic cylinders to overcome this particular difficulty. Mr. Forbes mentioned that in the case of Messrs. Greenwood & Batley's pumping unit the objection to bye-passing the oil through the safety valve had been overcome by elaborating the control valve, so that when the gear pump was shut off, the safety valve was put out of action. That is a very great advantage and it avoids the trouble due to heating the oil from that cause.

Mr. Wilcock mentioned the use of hydraulic power for chucking. Well, we have never heard of that being used until Mr. Liebert mentioned just now that he has seen it on American machines. There does not seem to be anything impossible in applying hydraulic power for that purpose. Mr. Shaw does not see why screw-cutting is not possible with hydraulic drive. Well, I suppose that theoretically it is, but practically it is impossible to get the speed of the driving end in exact relation to the speed of the pump end. With screw-cutting you must get the speed of the lead screw to within fine limits, and although it is quite impossible with hydraulic gear to regulate the speed to within, say, one per cent. or perhaps 1/10 per cent., this is a long way off the requirements for this particular purpose.

Mr. Gorst : I would just like to add my tribute. I, personally consider the lecture an excellent one in every respect. I submit to you that the work of the pioneer is somewhat hard, and these gentlemen are pioneers. If what they have told us about this subject of hydraulic transmission is disturbing us, then it is doing very useful work—it is making us think. My personal opinion is that we have seen and heard a great many things that were very interesting, and which will loom very largely in engineering matters in the future. I have been very delighted to hear a lecture so excellently prepared and so excellently rendered, and I add my tribute of praise to the lecturers for the very able manner in which they have done it.

A cordial vote of thanks to the authors was adopted.

Communicated by the Authors.

With regard to the compressibility of water, there is a large amount of detail information available covering the compressibility at varying temperatures of pressures.

With regard to oil, Mr. Hyde in the *Proc. of the Royal Society* A.97, 1920, hes published the results of experiments on castor oil, sperm oil and Mobiloil A at 40 degrees centigrade, and pressures at one to five tons per square inch. Mr. Hyde states that the bulk modulus varies from 242,000 to 315,000, so that we think that the rough figure given in the discussion of 1/3 of one per cent. for every thousand lbs. pressure per square inch, will be found sufficiently accurate for the requirements of machine tool designers.

A visitor raised the query concerning economical operation of four separate slides on one machine. Many of the photographs showed a number of slides operating from the same pumping unit, in most cases one motion only was operated by the high pressure liquid, the remainder being controlled by separate valves from the low pressure provided by the gear pump. However, in cases where it is required to operate several feed motions from the high pressure supply the arrangement mentioned in the Paper could be adopted whereby the variable stroke pump is automatically controlled by a piston and spring so as to keep a high pressure supply pipe under approximately constant pressure which pipe can be taken round the machine, various feeds have worked off it by means of valves. It will be evident that there are almost an infinite number of possible variations in the exact method of applying hydraulic feeds.

Mr. Chipperfield in his remarks mentioned a case in which the variable stroke pump was put on the exhaust end of the cylinder instead of on the pressure side, and Mr. Forbes referred to the possibilities of open circuits against closed circuits. To arrive at the best possible solution to meet the needs of any particular case calls for close co-operation between the machine tool designer and the hydraulic engineer.

Discussion, Coventry Section.

MR. I. H. WRIGHT: I would like you to help the machine tool makers who have to design these machines a little more than you do by simply offering a good pump. There are quite a lot of things in design, apart from buying a pump. What I have in mind is some data which will enable us to calculate the necessary dimensions of piping, valves, etc. A lot of auxiliary motions use low pressure oil, and unless the pipes are suitable you get a very slow creeping kind of motion. A good deal has been said, and quite necessarily, about the importance of the fluid being solid and only having its own modulus of elasticity to suffer for. It has also been said that air can be kept out of the oil, but after strenuous efforts I do not think it is possible for this to be done. Is there any liquid which is less liable to emulsify, and more anxious to separate from its air, than oil ? In connection with the hydraulic rotary transmission. With the new high speed cutting materials, we are very nervous about the possibility of chatter. I suggest that there is a possibility of this being eliminated by slight changes in speed breaking up the synchronism of the chattering parts. There is no doubt that in rotary motions in ordinary machine tool operations, if we get up to a maximum commercial cutting speed it is not unlikely that some vibration of the parts sets up undesirable conditions. If the speed could be altered two or three per cent. either way quite easily, it would probably allow us to get somewhere nearer the maximum speed and still avoid chatter. You referred to a hydraulic shaper. I saw one about two years ago and was surprised to find they used a hydraulic pump and rotary motor through slot-link mechanism. The slot-link mechanism does not give a uniform cutting speed, and it seemed to me a very serious omission. A planing machine I think would be very difficult to reciprocate hydraulically. In such machines the cutting tool tends to chatter along the work, and it seems to me that the hydraulic cylinder would be under a great disadvantage.

MR. BEACHAM: If the planer could be altered to reduce its tendency to chatter it should be the ideal case for a hydraulic drive. You ask about the friction of the oil in pipes. With hydraulic gears working at, say, 500 to 1,500 lbs. per square inch, the usual practice is to use pipe velocities of six to 10 feet per second, but it is possible that when you come down to 100 lbs. per square inch somewhat lower velocities might be advisable, but I doubt it. The pipes on a machine tool are very short, and with velocities of that order I doubt whether you would get any appreciable loss. In regard to air, you can only have an air-free hydraulic system if the air will leak out faster than it can get in, and it does not sound a very difficult thing to do, but we know from experience that it is difficult,

as you have to be continuously on the watch, and it has to be guarded by sealing those places where there is a chance of vacuum in the place of oil over atmospheric pressure. In the work we have done hitherto a solution has always been possible, and I frankly do not believe that it is not possible to design any machine tool feed so that air is eliminated. In regard to rotary transmission, there is more than one type of hydraulic gear that is absolutely technically suitable for the rotary drive, but it is the cost of production every time that is the real drawback to its application. It can only be used for those purposes where the exact control of speed is worth paying the high price. With the reciprocating transmission it is a different story. You referred to the slight change of speed breaking up synchronism. I imagine that would be one advantage of using a variable speed gear. We have seen the descriptions of a shaper operated from a hydraulic variable speed gear, and it seems to me that it is an entirely wrong method. I cannot see much advantage in employing a rotary hydraulic machine, and then having the disadvantages of unequal motion from that to the tool. In regard to the hydraulic planer, your remarks are of great interest, because this machine gave a great deal of trouble at first.

Mr. Wray: There seems to me three problems in regard to machine tools—those which we tackle, those which we ought to tackle, and those which we might leave. I agree with Mr. Wright in regard to planing machines, as I feel that the hydraulic drive is the right drive for a planer. Have you had any experience in regard to bleeding the air away from the system? Another point is in regard to ordinary feeds, particularly milling machine tables where the piston must definitely be gripped on both sides. Have you had any experience with that? I believe the Cincinnati people have definitely overcome that. The other thing which I think should be tackled is a boring machine table. This seems to me to be an ideal subject for a hydraulic pump. The things which might be left for a long time are, I think, lathes, for this reason—not only is the headstock difficult, but at present we have to provide all the mechanism for the screw-cutting, and we may as well use that mechanism.

Mr. Beacham: As far as our experience goes, it is quite possible to bleed air through capillary passages. As long as air is not leaking in faster than the piston to the pump will let it out, you get an air-free piston. The air will also pass a gland or sliding joint. The pump itself is the best point at which to arrange for the air to be removed because it is rotating and the air is carried by centrifugal action to a point at which it is exposed to a passage between the piston and the cylinder. In regard to back pressure arrangement of the Cincinnati machine, as far as we know a pressure pipe is supplied through a valve to the cylinder, and the back pressure

pipe is fitted with a metering pump. The boring machine was mentioned as being suitable for hydraulic feed, and we are very pleased to hear this. As far as lathe feeds are concerned, the arrangement of a ram type of feed would be a very difficult matter.

MR. WRAY: We were rather interested in trying to circulate oil under a vacuum. Have you had any experience of that? We firstly tried a reciprocating pump, then a plunger pump, and then the Hele-Shaw. We got a higher vacuum with the Hele-Shaw, but only obtained nine inches of mercury. The temperature was 400° F We could not get better than two lbs. pressure at that temperature with the reciprocating pump; we got to about two inches with a positive piston pump, but with the Hele-Shaw we got up to nine inches.

MR. BEACHAM: Possibly the explanation would be that you are getting vapour generating under the heat and vacuum. Perhaps with the Hele-Shaw the results were better because of small clearance volume.

MR. HEY: In regard to the back pressure of the oil, am I right in surmising that the Cincinnati machine has pressure on both sides, and the machine is controlled by relief valves instead of by extra pressure?

MR. BEACHAM: The motor is controlled by the variable stroke pump instead of the flow being throttled through the valve.

MR. HEY: By increasing the pressure on both sides of the piston would it not be possible to wipe out chatter? What is the best grade of oil to use when this type of pump is used? Is there any question of scoring of the pistons due to dirt or other foreign matter getting in the system?

MR. BEACHAM: As regards chatter, if this is due to the compressibility of the oil itself, the back pressure system adopted, and the system shown are both the same. If it is due to air, putting back pressure on the system will help matters. The best kind of oil to use is a pure mineral oil, which must be as thick as is consistent with using fairly small pipes. It must not be too thick to flow through the pipes, and yet it must be thick enough to lubricate the pump. The Vacuum Company have had long experience, and their advice would be useful for any particular application. For outside applications a non-freezing oil is essential, but for work such as machine tools a slightly thicker oil might be an advantage. In regard to dirt in the pumps, every effort must be made to keep it out, particularly when the machine is new and when it is first started up. It would be advisable to clean out the system after it has been run for some time, but the pumps, being rotary pumps, the dirt does not do as much harm as would be expected, because it separates inside the pump. It is only the initial dirt which has

to be dealt with. There is nothing like cast iron for cylinders and pistons.

MR. COLE : In describing the pump, I think the lecturer remarked that there was a difference in its performance when first started up. I would like the lecturer's version as to whether there is a difference when started up in the morning, and after it has been running for, say, some two or three hours. If so, what is the difference ? Also, can he tell me what is the slip of the pump when it is working at full stroke and maximum pressure ?

MR. BEACHAM : When I mentioned that a pump might behave differently after running for some time, that was in connection with the arrangement shown in Fig. 1 where an air pump is used through a safety valve and the hydraulic pressure is regulated through a throttle valve after that. In that case the gear pump would heat the oil, the oil would get thinner and flow more easily through the valve, therefore, in that particular case the feed would get faster the longer the machine was operated, but by using a variable stroke pump that is cut out, and you should get the same speed and feed whatever the temperature is. The slip would be something in the nature of four or five per cent. of the capacity of the pump for every thousand lbs. pressure ; 500 lbs. pressure would be half that, 250 lbs. pressure would be one-quarter.

MR. KNIGHT : What is the maximum pressure at which these pumps can worked for continuous duty, say, for a whole day ? What is the maximum temperature to which it will rise when it is working under the conditions mentioned ?

MR. BEACHAM : We have had pumps working continuously, that is under pressure the whole time, up to 1,200 lbs. per square inch. I presume you mean when the pump is continuously under pressure, but the stroke is being automatically controlled. The oil is not being used the whole time, but the pump is under pressure the whole time. The temperature of the pump might run up to 100 or 120° F., and under those conditions it might be necessary to use perhaps a little thicker oil than when the pumps do not run so hot, but there is no difficulty in running them at that temperature. The requirement is that the oil must be sufficiently viscous at the working temperature of the pump to efficiently lubricate it.

MR. GRIFFITHS : I was very interested in Mr. Wright's reference to the " Magdeburg " lathe, and despite the opinions expressed in the discussion, believe that there is a vast scope for developments of hydraulic transmission for rotary cutting, if only to eliminate the margin line of dropping into back gear on a hard specimen with its accompanying tooth chatter, and am accordingly anxious to know whether the pulsations of the pump would have any effect when desiring a fine finish. Machines of push and pull type present less of a problem to actuate, but what is the degree of accuracy in

registering, and how much is this affected by change of temperature. The mass of weird flexible shafts in a submarine, surely gives scope for an easier assembly of hydraulic transmission.

MR. BEACHAM: The difficulty in regulating only occurs when you are using a valve to regulate the speed. In the Magdeburg lathe the gear is a combination of a variable stroke pump and fixed stroke motor, and the regulation of the speed should be independent of the load.

A VISITOR: I take it that the pump mechanism is a great advantage in eliminating vibration. I have had a great deal of experience on a lapping machine for lapping gauges. We have an electric motor which drives the motor by silent chain principle, and I wondered whether it would be an advantage to put a rotary pump on to the lapping machine to see whether it would do away entirely with vibration.

MR. BEACHAM: I certainly think hydraulic drive, being through the medium of something which is slightly elastic, would eliminate vibration and give freedom from trouble.

The proceedings closed with a cordial vote of thanks to the authors.

THE APPLICATION OF HYDRAULICS IN DESIGN.

Paper presented to the Institution, London Section, by G. W. Betteridge, M.I.P.E.

ALTHOUGH the title of this paper is **The Application of Hydraulics in Design,** it is my intention to deal in this paper only with that side of hydraulics which concerns the practical application of hydraulics in the design of machine tools, conveyors and other applications using the new high pressure variable delivery pump, which are of particular interest to the production engineer.

It is, however, permissible to say a few words about the origin of hydraulics. The actual principle of hydraulics was first conceived by a Frenchman, named Pascal, who made the statement that, " If a vessel full of water and closed on all sides has two openings, the one a hundred times as large as the other, and if each be supplied with a piston which fits it exactly, then a man pushing the small piston will exert a force which will equal that of one hundred men pushing the large piston, and will overcome that of ninety-nine."

It remained, however, for an Englishman named Joseph Brahmah to discover how to apply this principle, which resulted in the conception of the Brahmah hydraulic press, for various purposes requiring large forces. This discovery and application was made towards the end of the eighteenth century. The machine attracted very great attention in this country, and there are many such presses still in use. These early hydraulic presses were later operated by power driven pumps. In each case, the output of the pump was applied direct to the ram, so that, for each stroke of the plunger, the ram advanced a definite amount. The pumps used, however, were not capable of delivering large volumes, so the movement of the ram was very slow.

The popularity of this new invention increased with the development of the basic idea and was considerably furthered in 1850 by W. G. Armstrong (ultimately of Vickers-Armstrongs), when he invented the accumulator, which enabled the pump to run continuously and store up the fluid under pressure until required. But towards the end of the nineteenth century, it seemed that this invention had been developed to the limit of its possibilities, as it then fell into some disfavour, owing to various faults, which have not until recent years been overcome. But even so, there are still a number of disadvantages, which have prevented its incorporation in the design of machine tools, namely :—

5th March, 1931.

(1) Power is dissipated, because the pump delivers fluid at the maximum pressure, irrespective of the pressure required to operate the ram. For example, the pressure required to move the ram up to the work may be very small, say 10 lbs., because the only resistance is the friction produced by the working parts ; but the fluid is pumped at a pressure of, say, 1,000 lbs., so that 99 per cent. of the power is wasted.

(2) The hydraulic system using water requires constant attention and frequent replacements are necessary, owing to the cutting action of the fluid wearing the valves and seats.

Although other types of hydraulic pumps were conceived and patented, this did not alter the fact that the hydraulic art became static until about 1890, when a few engineers began to think of the possibility of developing multiple plunger variable stroke pumps, of a type similar to those which are fully developed and so widely used to-day. The modern volumetric pump (as it is called) has several plungers ; is driven at high speed (800 to 1,000 being frequent), and is of variable stroke. It can deliver a smooth flow of fluid at high efficiency, some pumps now made having an efficiency of over 90 per cent. at full load, and can be directly coupled to high speed driving units, such as electric motors.

But the successful application of hydraulics to machine tools, using a variable delivery high pressure pump, did not begin, I believe, until the introduction of the hydraulic Broaching Machine, in 1922. This machine was installed in a U.S.A. works, in March, 1923, the first job put on it being a differential gear with a six spline hole. The cutting speed used was 11 feet per minute, and the production obtainable was 70 pieces per hour. The performance of this machine, and its effect on the life of the broach, caused designers to look more closely into its possibilities, which has assisted very greatly in its development.

It is of course known that no transmission of energy can take place without loss in some form or another. The form of this loss varies according to the method of transmission, and the amount of loss varies according to design or mechanical imperfections of the machine or device used for such transmission. For example, when using a belt drive for a pair of pulleys, the loss is mainly due to the slipping of the belt over the surface of the pulleys, and a loss of motion is the result. If a chain and sprocket drive is used, the loss is entirely due to friction, and no motion is lost, as the drive is positive. With this method of transmission, there is a loss of effort or force. Such losses are expressed in terms of efficiency, that is, of the ratio of useful work available after transmission to the useful work put into the transmission. In hydraulically operated machines it is proved that the efficiency is very often double that of a similar machine operated mechanically.

Machine tools can be put into two classes, namely, the straight line cutting (reciprocating motion), and the rotary cutting, and, in both cases, the essentials are the same, to wit, the tool must cut at a certain speed in feet per minute, and the work feed be applied to the tool at a certain speed in feet per minute. In order to obtain these speeds and feeds, the cone pulley was first used, and later the gear box. In each case, the speeds progress in steps, and there are many and varied ingenious methods used for narrowing the gaps between the steps by mechanical means.

The tendency, in improving the design of machines, had been by multi-speed gear and feed boxes, and elaborate mechanical devices for travel control, and there are many cases where this has resulted in levers and handles jutting out at all angles ; but this elaboration of the old type of machine had not fully met the modern needs. What it gained in facility, it lost in rigidity, speed control, simplicity of operation and life, and the demands of modern production, are such that standard model machines, even with careful use, develop backlash at a rate which is alarming.

These facts have undoubtedly had a great influence on the general adoption of hydraulic feeds, which have also shown their ability to absorb and dissipate energy harmlessly ; maintain a feed once set, irrespective of the resistance met, less a slight slip, about which I shall talk later ; and provide a cushioning effect to forces, with most remarkable results. In fact, we could liken this effect to falling from a height on to a blanket stretched out below (as is done by firemen), compared with falling from a height on to the hard ground, with the consequent shock.

With the problem confronting them, of constructing machines more rigidly to withstand the severe strains and stresses imposed on them by the use of new high duty cutting alloys, designers are now, more particularly perhaps in America, incorporating hydraulic transmission wherever possible in their latest designs, and if the designer of the future will study the human factor in relation to hydraulics, he can by their use, more readily reduce the fatigue factor particularly in the performance of those operations which affect the operator physically.

Many engineers have put their efforts into the development of the modern volumetric pumps and units ; a complete list of inventors in this field would include at least three hundred names—a striking tribute to its possibilities. In fact, many papers could be read on the theme of the lines along which the modern pump has been developed—the various factors which have affected the design, and and the results ; but it is established beyond reasonable question in that there are now almost unlimited varieties of functions available, with many advantages over mechanical means.

The main advantages of hydraulic feeds over mechanical feeds,

can be summarised under the following heads :—

Flexibility ; Their cushioned effect on tools ; Ease of control and safety factor ; and lower power of consumption.

Flexibility.

When designing a machine in which hydraulic feeds will be used, it is not necessary to specify accurately the rate of feed required, but only to determine the minimum and maximum rates, after which the most efficient rate of feed can be determined experimentally when the machine is operating. Further, the unit can be placed in any position convenient to the designer, as even the most complete hydraulic outfit consists only of pumps, valves and cylinders or motors, and excepting in the case of the cylinder (which, of course, must be put in the same plane as the feed), the outfit can be put into any convenient spot, and connected by piping.

Cushioned effect on tools.

It has been proved by exhaustive tests that the compressibility of a hydraulic medium is very closely associated with the increased life of the cutting tool. It is difficult to determine the actual increase, but a 50 per cent. longer life of tool can be looked for, on an average. Slip, which is that amount of oil which leaks past the cylinders and the piston in the ram, was considered at one time to be a serious draw-back, but it would now seem that this has largely contributed to the great savings made in tool costs, and the absorption of shock by providing the cushioned effect referred to.

As the variable stroke pumps used to-day are made to very fine limits, the leakage, when using the correct oil, is a very small percentage of the maximum delivery, even at high pressure. It is, of course, important that the oil specified by the various makers of pumps should be used, as a rise in temperature decreases the viscosity of an oil, but the amount of such decrease varies considerably with different oils. For example, castor oil, at 60 deg. Fahr., is very viscous, and sperm oil, at the same temperature, is a thin oil ; yet, at 200 deg. Fahr., there is very little difference between them. It is, therefore, quite evident that, if the gear produces any appreciable rise in temperature, it is useless to adopt a viscous oil to prevent slip, but, as already explained, this is no defect, but an advantage. This amount of leakage is greater as the pressure rises, which results in a reduced rate of feed, the loss never being made up. Hence the tool is not damaged by being forced to maintain given feed rates, as may be the case when overload causes winding up of the mechanical feed gear.

The possibilities of this wind developing are best shown on Fig. 1, which illustrates on a vertical drilling and boring machine, through the necessary change speed gear box and driving shafts, nine stages where this may take place between the prime mover and the tool.

Safety factor and ease of control.

In mechanically operated machines, the safety factor is sometimes taken care of by means of couplings pinned together with a pin sized to shear at what is considered the danger point. This, in special machines, is a disadvantage to the designer, inasmuch as the contributory causes to the pin's shearing are not always known. In hydraulically operated machines, however, the designer will have determined the maximum feeding force required, and, by setting a relief valve in the pump, arranged to blow at this determined maximum pressure, the possibility of damage to the machine or cutter through overload is eliminated, the blowing of this valve ensuring the feed being automatically stopped, and the load taken off the tool.

FIG. 1.

There is an important advantage, as the danger point might be reached while the attention of the operator has been diverted for a moment.

On mechanically operated machines it is largely guesswork on the part of the operator as to when the tool needs changing, but hydraulically equipped machines are usually fitted with a gauge, and, by referring to this, the operator is able to determine exactly when the tools need re-sharpening. In addition, the cut can be changed at any time during the operation, to suit conditions, without damage, so that a gradually decreased feed, when the cut becomes excessive, as in the case of large fillets in castings and forgings, is obtainable.

Lower power consumption.

There is definitely a lower consumption of power, when feeds are operated hydraulically, than with mechanical feeds ; probably the greatest saving from the new hydraulic feeds is made in the case of presses. In a comparison with a hydraulic accumulator and pump, the saving is 70 per cent. to 80 per cent., as power is consumed only according to load.

Hydraulics, being perhaps somewhat a sphere unto themselves, call for very close co-operation between the hydraulic engineer and the machine tool designers, but generally, as examples, the points needed to determine the correct outfit for feeds are :—

(1) The force in lbs. required to move the slide for rapid traverse.
(2) The force in lbs. required for feeding.
(3) The rate of rapid or differential approach required.
(4) The minimum and maximum rates of feed desired.
(5) The minimum and maximum length of stroke required.
(6) How many operations are to be performed to complete the cycle.
(7) Is it required to be automatic, semi-automatic or hand-controlled only.
(8) Are there auxiliary functions required, such as chucking, clamping, indexing, feeding of bar stock, etc.

For continuous reciprocation, as in the case of grinding machines, honing machines, etc., the information needed is :—

(1) What is the minimum and maximum rate of feeding required.
(2) What is the weight of the moving member.
(3) Is it constant.
(4) If not, what is the maximum force required.
(5) What type of finish is required, and what type of wheel is to be used—cup or periphery.
(6) What auxiliary functions are required.
(7) Minimum and maximum stroke.

Hydraulic pumps, used to provide these varying functions are, in principle, all the same, inasmuch as they pump oil at various pressures with varying degrees of efficiency ; but by the introduction of control valves, stroke changing mechanism, etc., they are arranged for different purposes, and the main divisions into which they fall, by reason of the work they perform are :—

Constant delivery pumps.
Variable delivery pumps.
Constant pressure pumps.
Variable pressure pumps.

A simple type of constant delivery pump is the gear pump, which is a type of pump you see on many machine tools, for supplying lubricant to the cutters. This type of pump, made in varying sizes,

will also deliver large volumes of oil at pressures even up to 300 lbs. per square inch. This pump is used mainly for reciprocating purposes, but should be used only where the load and speed are constant. It is also used for auxiliary purposes, in conjunction with a high pressure pump. When applied to machines using metal cutting tools, it usually necessitates having large ram areas, increased volume, large pipes and valves, which, if space permits and load is constant, are, of course, quite permissible ; but if the feed or load is a varying one, this type of pump is not so satisfactory, as, being a constant delivery pump, it entails the use of choke valves for by-passing any oil which is not being used, causing overheating and possibly irregular feeding.

There are, of course, many uses for a gear pump in hydraulics, as, when used in conjunction with a high pressure pump, it provides a

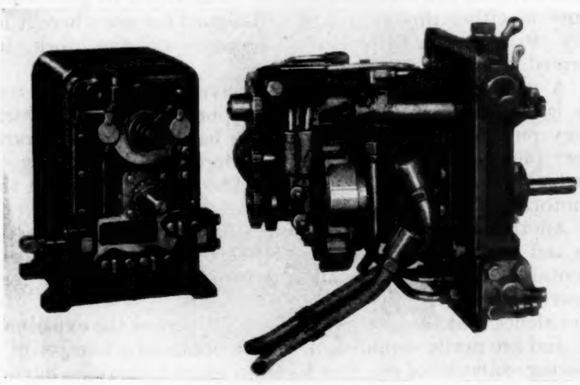


FIG. 3.

supply for auxiliary functions, among them being the provision of rapid traverse, indexing, clamping, etc.

Slides of the following machines were then shown by the lecturer, but it has not been found possible to reproduce more than a few illustrations here.

A variable delivery high pressure pump, which, having an adjustable stroke, can be set to deliver just the exact amount of oil required in either direction for the given rate of feed, plus unavoidable leakage, with which I will deal later.

Fig. 3 shows another variable delivery pump which will provide seven functions : Rapid traverse ; fast feed ; slow feed ; neutral ; and the same motions reverse, all of them variable within a ratio of, say 1 : 20.

You will notice how suitable this is for unit construction and incorporation in the design of machine tools, inasmuch as the outfit in question is a complete unit comprising a high pressure pump, low pressure pump (which cannot be seen), control valves, stroke changing mechanism and automatic stroke control.

4. A self-contained high pressure variable delivery pump arranged to give constant pressure. The arrangement inside this pump provides that a constant volume of oil, at any pressure in either direction up to its maximum (of, say 1,000 lbs. per square inch), can be maintained, regardless of the resistance met. Pressure with this pump can be maintained indefinitely without attention, which is an invaluable feature for application to Bakelite and similar presses, where pressure is required to be held for any length of time. The control valve shown has four positions.

5. A variable delivery pump, which is arranged to give variable pressure in either direction, and is designed for use where it is necessary to obtain a variation in pressure on the work being performed.

6. A combination of a variable delivery pump and a motor, which is used for rotary motion. The pump is the usual variable delivery pump, and the motor has the basic design of a variable delivery pump. The motor obtains its force and its varying speed through the variable delivery pump. This is the pump and this is the motor. This shows another type.

7. Another combination of pump and motor. In this case, the pump and motor, being connected by pipe lines, instead of being a self-contained unit, perhaps allow a little more flexibility for the designer.

As evidence that the new hydraulics have passed the experimental stages and are firmly established, I have obtained a number of very interesting examples of machine tools, to which hydraulics have been very successfully applied, and, in some cases, I have also been able to get particulars of the production, which was obtained from them, together with the savings in tool costs. Some of these figures are very striking.

8. A hydraulic horizontal Broaching Machine. Over a run of a year, the user states that his production was trebled, with a large reduction in tool costs. Speeds increased from five feet per minute to 12 feet per minute ; it is possible to cut at 20 feet per minute on this size of machine.

9. A Twin Spindle Broaching Machine, which is broaching Houdaille Shock Absorber Parts. The production on the radii on the wings and wing shafts on this machine was at the rate of 400 pieces per hour. This machine is fitted with an automatic control valve for continuous operation.

The number of pieces produced without re-sharpening the broaches

varied from 32,000 pieces to 38,000 pieces, equivalent to 10-12 working days of eight hours each.

10. An interesting Hydraulic Broaching Machine, which has a stroke of 76 inches, and a peak pull capacity of 150,000 lbs., which is nearly 70 tons. This machine was designed for broaching locomotive and tractor wheels, and is capable of broaching a 10 inch diameter hole.

Following closely on the heels of the application to Broaching Machines, hydraulics were applied to Drilling and Boring Machines, and are now considered a standard feature by the majority of

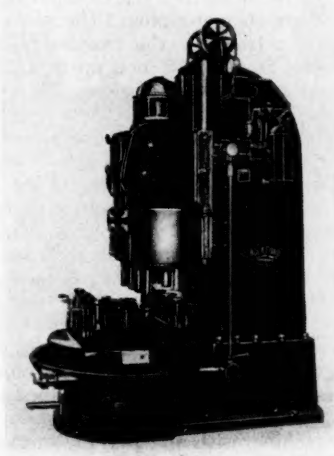


Fig. 11.

Drilling and Boring Machine manufacturers. The savings in tool costs have been astounding, in addition to which it has been found possible considerably to increase the cutting speed.

Fig. 11 shows a vertical Multiple Spindle Boring and Drilling Machine, which illustrates what is practically a continuous operation, the whole cycle of which is performed hydraulically. What happens here is that the operator loads four connecting rods, steps on the foot pedal, which raises the table off its seat, then indexes the loaded fixture under the spindles and releases the pedal, when the table locks itself hydraulically. The operator then starts, by means of this handle, the automatic cycle of rapid approach, feeding, and then rapid return. While this cycle is taking place, the operator is loading another station.

12. A horizontal double-ended Multiple Spindle Counterboring Machine, which operates both the heads through a mechanical equalising device, fitted to the two cylinders, to ensure that the timing synchronises. The indexing drum is hydraulically located and locked, and is controlled by means of the pedal shown in the front of the machine. At each indexing of the table, the operator unloads a housing, finished machined, and loads another one.

13. A two-way horizontal Drilling Machine. The machine is fitted with two separate variable delivery pumps, shown here. The semi-automatic hydraulic feed ensures that the machine, by simple pressure of a button, performs the cycle of rapid approach to the job, feed, and rapid return, then stopping. The piece being drilled is a transmission case of a tractor ; the two heads are fitted with 60 drills, varying in size from 21/32 inch up to 1-23/32 inches. The production obtained was 18 pieces per hour.

14. A three-way Drilling Machine. The three heads are operated simultaneously through one variable delivery pump, which gives a cycle of operation as follows : Quick approach of the drills to the work ; drilling feed ; and quick return to the starting postion. Separate feed cylinders are used for actuating each head, and a simple load and fire dog type of control is mounted on the upper vertical head, and controls the stroke on all heads. This control is shown here, and, by the use of a simple mechanical equalising device, it is ensured that the heads cannot get out of timed relation to one another. As in the case of the former machine, the production from this is interesting. The machine shown was arranged for drilling 103 holes on three sides of a cylinder block, varying from 3/16 to 9/16 inches, and the production obtained was 60 pieces per hour.

15. A similar machine, with an equal production, but built with one vertical and two horizontal heads.

Fig. 16 shows an ingenious application of hydraulic feed. You will notice that the three heads are set at different angles, and all three heads are operated by one variable delivery feed pump, and one cylinder. This cylinder is directly connected to the central head, and the feed is passed on to the two side heads by means of mechanically operated links, as shown here. The automatic cam control shown here provided for rapid advance to the work : adjustable drilling feed : second rapid travel between two drilling surfaces, and a second adjustable drilling feed, which is the same rate of feed as the first : then a rapid return to the loading position. This is done through simple forms of dog cams. The mechanism here is arranged in a universal manner. The movement of this handle operates this rack and segment, which, in turn, operates the splined shaft, which, through a further pinion gear, not clearly shown, operates in turn directly through the adjustable cams, which operate the control

valve, and so the varying cycles previously explained.

The pump providing all this is driven by a one h.p. motor. Four of these machines are reputed to take care of the peak of the production of the Ford model A. cylinder blocks, drilling the lubricating holes from the valve tappet chambers to each of the main three bearings.

17. A special heavy duty Boring and Facing Machine, which was used for the boring and facing of locomotive car wheels. The machine is fitted with three variable delivery pumps, all of which

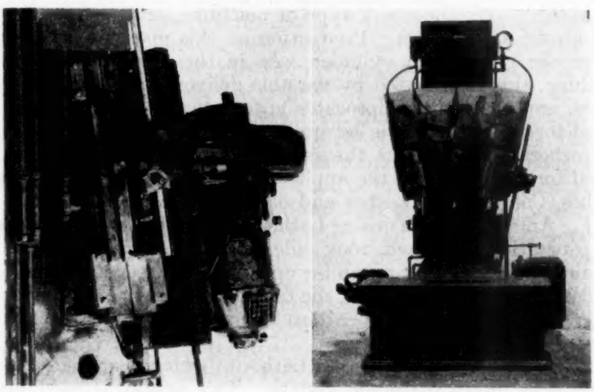


Fig. 16

are driven from one constant speed motor. Two pumps were used for chucking the car wheels, and the third for feeding the boring heads. These two heads were each fitted with a cylinder, working in parallel, the diameter of the cylinders being nine inches. The minimum feed required was .050 inch per minute, but, even so, there was available a rapid traverse of 100 inches per minute, and a feeding force of 100,000 lbs. The design in this case of the feeding and clamping forces is simple in the extreme, requiring only pumps, cylinders and rams, with the necessary piping for connecting.

For Grinding Machines, a simpler type of pump is permissible, particularly for cylindrical grinding, but, where the question of inertia has to be considered, which is especially the case in Surface Grinders and large Grinders, such as Roll Grinders, it is advantageous to use a high pressure variable delivery pump.

18. An interesting application of a low pressure pump, of variable capacity, which has an advantage over the gear pump, inasmuch as it does not transmit vibrations. The machine is a Semi-Automatic

Hydraulic Cam Grinder. The hydraulic circuit provides for the complete grinding of a cam shaft automatically.

19. A machine which is driven by a high pressure variable delivery pump, with two small single acting feed cylinders mounted in the bed of the machine, directly below the table. This, with a valve, provides reciprocation at a variable rate of speed, an infinite number of speeds from 9 to 55 feet per minute being available, by simply turning a handle on the front of the machine. Cross feed on this machine is also operated hydraulically.

20. A single spindle Honing Machine. This possesses many advantages over the crank type of machine, inasmuch as the feed and stroke are uniform. Production on this machine was reputed to be one minute per cylinder. As in the case of the Grinding Machine, this is operated by variable delivery pump, cylinder and valve, and the head reciprocates automatically at any stroke and speed for which it can be set quite easily.

Nowhere, perhaps, has the skill of the hydraulic engineer been called for more than in the application of hydraulics to Automatic Lathes, Combination Lathes and ordinary Centre Lathes.

21. An Automatic Turning Lathe, which is driven by two pumps, one operating the front tool slide for both feed lengthwise and forming, and the other pump for operating the rear cross slide, in a similar manner. In this case, the tailstock is also operated hydraulically, the supply for this operation being taken from the low pressure pump.

22. A high duty Production Lathe, to which is applied a simple single gear pump hydraulic system. This supply is used for the movement and control of the slides both lengthwise and crosswise, and the illustration shows the machine fitted with a hydraulic cylinder screwed to the mandrel end for working a draw bar chucking system. The piston, in this case, is integral with the shaft carrying the oil inlet and outflow, revolving with the mandrel. The shaft is bored through, so that draw bars can be inserted from the rear and readily adjusted. The system is also carried though to the tailstock, and, by the single movement of the lever shown at A, the tail barrel goes forward, the centre reaches the work, the movement stops, and the cylinder moves backwards automatically, drawing back the collet chuck, which in turn grips the tail barrel, locking it in position.

23. An automatic Crank Pin Finish Turning Lathe. This machine was designed and built for machining the webs and pins simultaneously of a six throw crank shaft. The cradle which carries the tools is actuated by a hydraulic cylinder, through a rack gear and toggle motion, one pump providing the necessary power. By use of the toggle motion, the speed of the tools automatically decreases as they near the pins. This is done by controlling the stroke of the pump. The production obtainable from this machine

is reputed to be a complete crank, on all six pins and webs, in three minutes.

24. An application of hydraulics to a lathe headstock, which reduces the necessity for gears to a minimum. In fact, it is possible, if one could determine a narrow margin of speed and horse power desired, to eliminate gears entirely, and connect directly to the spindle, obtaining between these two margins, whatever they might be, an infinite variation. There is an ingenious device fitted to the saddle, which enables a constant cutting feed to be maintained, by automatically increasing or decreasing the stroke of the pump commensurately with the diameter being machined.

25. A combination Turret Lathe. Using a variable delivery pump, and a combination of operating valves, feed cylinder and differential feed cylinder, provision is made for either semi or fully automatic cycles, when necessary. The circuit used on this machine provides a very steady feed, varying from 3/4 inch per minute to 19 inches per minute, and rapid traverse speeds, that is, approach and return, of 70 inches per minute. At each indexing of the turret, the correct feeding speed can be provided, and is controlled automatically. Regular and uniform feed is permitted, when cuts are intermittent. This is not permissible on a mechanically operated machine. The whole of this machine, except the headstock, is operated hydraulically.

26. A Vertical Milling Machine, on which the table is moved hydraulically, and which has a hydraulic circuit controlled by three pumps. This machine is fitted with a device for changing the feeding speed during the cut, and, with this device, it is possible to approximate constant power input into the cut, by running the table faster during those parts of a cut where only a small surface is being milled, and slowing it down when a larger surface is presented to the cutters. By means of this feature, which operates automatically, it is also possible to start and finish the cut slowly, running faster when the cutters are completely engaged in the work. Shocks to the work and the machine, which would occur when entering and leaving at maximum speeds, as would be the case with a mechanically operated machine, thus are avoided. The manufacturers of this machine also apply this system to a horizontal machine, in which the usual direction of cut has been reversed, and the performance of the hydraulic machine, compared with their best gear fed machine, showed an increase from 2½ inch feed per minute to 10 inches per minute, on a selected heavy form milling job. They also state that the increase in the life of the tool was exceptional, in addition to which, the finish was better.

Up until the introduction of the new hydraulics, the generally accepted method of applying power to hydraulic presses was through the use of the accumulator and pump, which, as I explained in the

beginning of this paper, has a number of inherent defects. But the introduction of the new self-contained constant pressure pump provided industry with a power transmission, which would deliver a high output in relation to consumption from the prime mover.

27. A 100 ton press, installed in a malleable iron foundry. This Press, at its maximum pressure, absorbs only 7½ h.p.

The advantages of straightening by this method, instead of by impact, are obvious, as, after the die strikes the work, pressure on the metal between the dies is held just long enough for the metal to

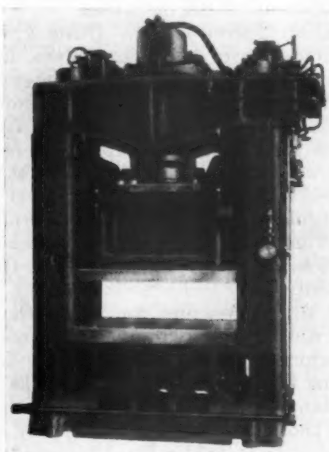


Fig. 29.

flow into its new alignment. The production, with two men, was 200 pieces per hour. Breakage of dies in this case is eliminated by the use of the safety valve, which is set to blow at a predetermined pressure.

28. A 100 ton Hot Plate Press, which is fitted with a variable pressure pump, and the advantage of a press so equipped is that it enables varying pressures to be obtained automatically, to suit the conditions and resistances, which the press meets during its cycle. Pressure on this machine can be held indefinitely.

Fig. 29 shows a 120 ton Sheet Metal Blanking Press. This was designed for use with very expensive dies, for a large electric concern, for automatic telephone switchboards. The production from this was 1,000 switchboards per hour, 16 inches wide, 52 inches long, of

.020 inch thick brass. A 1/16 inch stroke was used on this job, and the runs between grinding of dies were doubled.

30. Hydraulics applied to a Straightening Press. Anyone who has had to do straightening is acquainted with the physical effort required on this operation, which is entirely eliminated here.

31. A semi-automatic Press, for pressing brake spiders on the ends of rear axle housings. The whole cycle of operations on this machine takes only 40 seconds.

Fig. 32 shows hydraulic feeds applied to a Butt Welding Machine. On this type of machine it is necessary to hold pressure as well as provide feeds. This machine is welding the seams of an evaporator

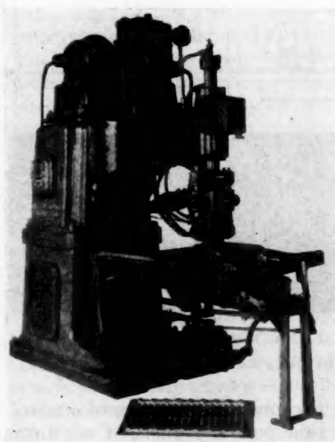


FIG. 32.

for use in electric refrigerators, but it is also used on an operation with which many of you are probably more familiar, the welding of rims of motor car wheels, where the production runs from 450 to 600 rims per hour, and on superheater flues for railway work, from 30 to 150 per hour.

33. Another type of Butt Welder, which is used for joining the ends of steel tubing. The operation required on this machine is that the tubes be advanced towards each other very slowly during the arcing, and then, at the proper moment, jammed together quickly, under a large force. This operation only takes a few seconds.

Fig. 34 shows the possibilities of the hydraulic system for Conveyor purposes. The lower photograph shows a hydraulic pump, which is

controlled by three cam four-way operated valves, which operate the pusher rods, which load the receiving elevators, shown here. The next cycle then takes the load up on to the next floor, the cycle bringing into use the elevating cylinders D. The truck is then passed on the track in the baking oven, which is controlled by the pusher rod and cylinder shown at D., and continues on to the other end of the baking oven, and by means of the elevating cylinders EE., is then transported right to the bottom floor, the unloading being done by

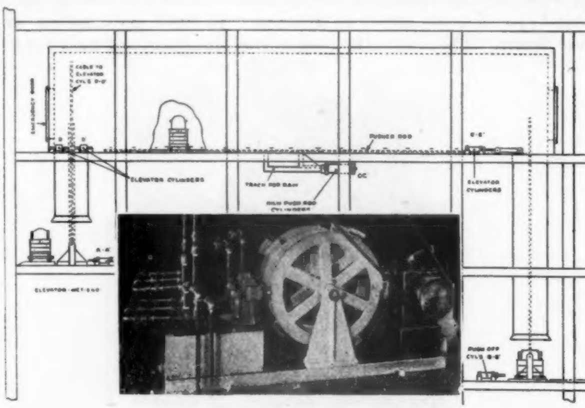


FIG. 34.

the cylinders BB. The possibilities, ease of control and variation of speed in this direction possesses distinct advantages.

To sum up—the advantages of the application of hydraulics to the design of machine tools are :—

Longer life of cutting tools.
Increased runs between set-ups.
Increased feeds, resulting in increased production, with decrease in supervision.
Longer life of machines.
Reduced maintenance.
Reduced effort on the part of the operator.
Lower power consumption.
In short—increased production at reduced cost.

No doubt, as time goes on, further advances will be made, but it can be truly said that the new hydraulics show one of the most rapid developments that have taken place in the history of the engineering industry.

Discussion.

MR. G. H. HALES said the illustrations shown by the author indicated the wonderful development that had taken place during the past ten years and there were still greater developments to come. It was now established that hydraulic movements were successful and that they had come to stay. Like most people who made revolutionary advances, the designers of hydraulic movements to machine tools had suffered because those into whose hands the apparatus first came, took liberties which they would never dream of taking with older and less efficient machinery, and having regard to the success that had been achieved, despite this, the designers were to be congratulated. The author's statement with regard to the constant delivery pump would be challenged by people better able to do so than himself. The statement was made that the constant delivery pump is unsuitable for heavy and varying pressures because of the difficulties introduced by the irregularity of feeding and by overheating. That bogey, however, had been fairly successfully laid sometime ago. Again, the author said, in regard to the variable delivery pump, that the necessary leakage was a help owing to the cushioning effect upon the life of the tools. It seemed to him that the advocates of the variable delivery pump were here making a virtue out of necessity ; at any rate he would like a little more enlightment on that point. As regards the illustrations shown by the author, they were all exterior views so far as the actual functioning of the hydraulic system was concerned and he felt it would have been more useful to have shown an audience of production engineers exactly how the system worked in the form of a diagrammatic representation in order that they could see exactly what was happening. The application of hydraulics was new and everybody was very much in the dark. Therefore it would have been extremely useful to have had some simple diagrams illustrating the movements which can be obtained.

MR. BETTERIDGE replied that he had merely stated that the constant delivery pump should not be used for heavy loads, and he had a very good reason for saying so. This type of pump relied on line contact against leakage. It should not be used for high pressure work. Again, this type of pump generated heat and he had shown in his curves how the speed dropped due to the increase in temperature. That was another reason why this pump should not be used for heavy work. As to the cushioning effect on the tools, the point was that with a mechanical broach, if a hard spot was found, the broach would be pulled through at a perfectly constant speed irrespective of the load on each particular cutting edge, but in the case of hydraulics there was a different action altogether. If that same hard spot was encountered, the load on the broach increased. It took more to pull the broach past that particular spot

and hence the pressure rose, the leakage increased and the speed decreased. The same would apply exactly in a lathe. As to the illustrations not giving sufficient information concerning the action of hydraulics, the point was that other lectures were being given on the subject in various parts of the country and he therefore had confined himself merely to a résumé of the development of hydraulics up to the present time. That was why he had left the technical side out of the paper. That was being provided for in the other Sections.

MR. V. GARTSIDE said he had been a little sceptical as to the application of hydraulics to machine tools, not because he did not think it was a good thing, but because he felt there was a great deal yet to be learned on the subject. Many years ago he had designed a variable stroke pump with a constant stroke motor, as the author had shown, but he got into all sorts of troubles with regard to valves and he dropped it. That idea had apparently been taken up since then and perfected. The thing he had been particularly sceptical about was the cushioning effect that had been mentioned. He could quite see the application of this to machines where there were light loads and quick movements, but when he had asked hydraulic engineers if they could arrange hydraulics for cutting a screw on a lathe, it seemed to give them something to think about. That, of course, was out of the question altogether, and it showed where hydraulics had to stop compared with the mechanical arrangement, where extreme accuracy was required. On a grinding machine, the cushioning effect in the ordinary sense did not matter but he could imagine it giving trouble on a drilling machine if there were a gang of drills at work and there was any cushioning, because there might be a chance of the drills jumping. He would like some information as to how that was provided for. The arrangement on the Cincinatti miller shown was an attempt to get over the cushioning difficulty when dealing with heavy goods such as locomotive connecting rods. He had had an arrangement described to him which appeared to put an enormous pressure on one side whilst releasing the pressure from the other side, in order to prevent cushioning, and he would like some information on that point. Also, what effect had the pipe line on the cushioning. Did the fact that there were kinks in the pipe have any effect on the cushioning due to the fact that the pipes might tend to put themselves into a straight position. He was rather inclined to agree with Mr. Hales that the advocates of hydraulics were really making a virtue out of necessity in this matter of cushioning, because the cushioning seemed to be there and could not be got away from. He would also like the author's view as to a comparison with the vane pump. Did the apparatus shown by the author go wrong? It seemed all right but it was very complicated. He could imagine a great deal of trouble unless they were made by experts. Even if the units could be bought ready to put into the machine there was

the question of repairs and it rather looked as if, by the introduction of hydraulics, it would be necessary to have an hydraulic engineer on the premises to look after the hydraulic part, in addition to an electrical engineer to look after the electrical part and a millwright to look after the mechanical part. Therefore, the question of reliability was an important one. It would be interesting to know how the cost of more modern arrangements using hydraulics and electricity compared with each other on a straightforward job. All the motions shown as being effected hydraulically could also be done electrically, for which there were elaborate arrangements of contactors and gears.

MR. BETTERIDGE said the cushioning effect on the tools is wholely taken care of by the increase in pressure and the increase in leakage. The effect of the pipe line did not enter into the matter. It was purely the effect of the pressure on the working parts of the pump and the system. There was leakage and hence loss of motion, and it was the loss of motion which took care of the tool. As to a comparison between the various types of pump, he gathered Mr. Gartside favoured the vane pump because it gave an even flow.

MR. GARTSIDE said he knew there are a lot of vane pumps being made.

MR. BETTERIDGE said the volumetric efficiency of the vane pump was low, which meant increased slip. There was excessive loss of motion and the result was that the feeds and speeds could never be relied upon. As regards the length of life of pumps of the type he had illustrated he had known such a pump to run for 15 years in the British Navy, working on steering gears and the wear was infinitesimal. The only wearing parts were the pistons and if there was any wear it was not fair wear and tear but was due to dirt in the oil system. In the same way, on the question of reliability, Navies all over the world were using these pumps and had been using them for 15 or 16 years. They were used for steering gears and watertight doors, and that fact should indicate they had proved reliable. He had never known a pump returned by a Naval authority through being worn out. As a matter of fact, there was nothing to wear.

MR. PUCKEY said that a feature of machines fitted with hydraulic equipment was the very high price, and he could only assume that this was due to the large amount of research work that had been put into them and had to be paid for. He could only hope that when it had been paid for there would be a considerable reduction in the price in the future. So far as the rotating movement was concerned, this did not appear to be so efficient as the reciprocating motion, and in that connection he asked for the author's opinion on the advantages, if any, of the hydraulic system as it was applied at the present moment to the rotating movement, in comparison, say, with a variable speed motor. It seemed to him that if a hydraulic system

was driven by a motor which was placed as near to the machine as possible and used direct in a certain manner, there would be a gain in efficiency. There were certain objections to the variable speed motor from the point of view of torque, but there were also some objections to the hydraulic system. He would like to hear from the author whether there had been any trouble due to air in the hydraulic system.

MR. BETTERIDGE speaking with regard to price, said he had discussed this matter with the machine tool people. The equipment was a precision job, but there was little doubt that the price of the units would be reduced considerably as soon as the machine tool makers patronised this form of equipment to an increasing extent. It was not claimed for the hydraulic system that it was any cheaper than any other, as such, but if the cost was based on so much per ton and on the useful output from the machine, together with the efficiency of the machines in the shop, then he claimed, that the hydraulically operated machine tool was much cheaper than the mechanically operated machine tool. It certainly was more reliable and did not require the same amount of staff to look after it. Moreover, the system took care of the tools and looked at from that point of view he claimed it was a cheap job. As to its advantages over the electrical drive or the variable speed drive, he agreed that it was impossible to get the maximum h.p. at the lower speeds with the hydraulic transmission, but the same applied to electrical drive. Generally speaking, he would not claim that there were any advantages over the electrical drive other than smoother operation, although he claimed that the life of the tools would be longer and the maintenance probably less. He had had a lot of trouble with people who had bought these hydraulic units with regard to air, but he always gave certain instructions how to avoid this. The trouble was to avoid emulsification of the oil through the air getting into the system, but there were means for overcoming that.

MR. F. W. M. LEE asked who are the makers of S.E.A. packing.

MR. BETTERIDGE replied that the makers are Ronald Twist.

MR. LEE then asked what is the best temperature at which to operate an hydraulic system having regard to the fact that the viscosity of oil varies with the temperature. Speaking with regard to the cushioning effect of the air in the system, he said this had been treated as an asset, whereas in his opinion it was a difficulty, because it was liable to lead to chattering.

MR. BETTERIDGE said he had not made the statement that the cushioning effect is due to air in the oil, and it was not to be considered in any way as an advantage to have air in the oil. This air did not provide a cushioning effect for the tool. There was no definite temperature at which an oil gear would work better than at any other, but as a general guide a temperature of 90 deg. Fahr.,

could be accepted. Actually he had worked gears up to a temperature of 190 deg. Fahr. It all depended on the nature of the oil and the conditions under which the machine was working. Under colder conditions, of course, a lighter grade of oil would be used.

Mr. Salmon asked what material S.E.A. rings are made of.

Mr. Betteridge said it is vulcanised fabric. In reply to another question by Mr. Salmon as to how the hydraulic system would operate in a bakelite moulding shop where pressures of 150 lbs. per square inch temperatures of 330 deg. Fahr. are required, he said there is an application of this kind in London operating three bakalite presses. The heat at which the platens worked had no effect on the pump at all. In the case in question, one pump worked the three presses.

Mr. C. C. Ferguson remarked that the author had confined his remarks to oil and had said nothing about working presses by water. He had been in a works in London recently and saw a number of presses—one of them a 1,200 ton press—working on motor car chassis frames and being operated by water. He had been told that oil would be too expensive.

Mr. Betteridge replied that water would be quite unsuitable for machine tools. It certainly was not cheaper than oil transmission, and its corroding properties meant the very careful selection of materials. All that could be done by water could be done by oil with a pumping plant half the size and costing half the price.

Mr. Gerard Smith referred to a centre lathe shown in one of the illustrations to the paper in which the controls were at least a yard or more apart. It had occurred to him that since the power had to be led by tubes to the acting position the whole control could be placed on one board and so prevent the need for the operator to rush up and down the machine to operate the various controls.

Mr. Betteridge replied that the centralisation of controls can easily be carried out. At the same time, in the case of machine tools with the various moving members, this might mean the use of flexible pipes which were undesirable, especially at high speeds. The use of pipes could be avoided altogether, however, and as a glimpse into the future it was certainly possible to put all the pipes out of sight inside the machine. In the latest machine tool fitted with the hydraulic system to come into this country, the controls were centralised and the whole of the hydraulic gear was packed away in the body of the machine in a space of about two square feet. The controls were in such a form that the operator selected what he wanted almost like a wireless set.

Mr. Bunnett asked what is the longest stroke that can be applied to an hydraulic machine. Would it be possible to use an hydraulic ram 30 feet long in a tube drawing mill.

Mr. Betteridge said that whilst it would be possible to use a

ram 30 feet long, there would be a considerable amount of deflection. It would be better to use an hydraulic motor coupled with a rack, which would give the same results.

MR. SALMON asked if the hydraulic system could be applied to the conditions which obtain in bakelite moulding. In the case of an 80 ton press, it was necessary to work first at 10 tons and hold it; then proceed to 20 tons and so gradually run up to the full pressure of 80 tons. If the full pressure was applied from the start the tool would be smashed. The period of dwell between 10 and 20 tons was one and a quarter minutes.

MR. BETTERIDGE replied that all this could be done automatically or semi-automatically with the hydraulic system and just as efficiently as by any mechanical means.

Responding to a hearty vote of thanks, Mr. Betteridge said he had had a great deal to do with the development of the hydraulic system as regards machine tools in Great Britain, and had been trying hard to get machine tool designers to understand it, and if anything he had said in the paper and during the discussion would help in that direction he would consider the paper had been well worth while. Up to the moment, America had shown us a clean pair of heels and had left us standing in this matter. Nevertheless, he believed that England would pull up. The variable hydraulic speed gear was invented in England and it seemed strange that America should have got the whip hand in the manner she had. America had been applying what we had originally invented and she was getting the benefit.

THE COLD WORKING OF METALS.

Paper presented to the Institution, Birmingham Section, by J. W. Berry, M.I.P.E.

THE object of this paper is to examine a few of the Cold Processes with a view to bringing them before the notice of Engineers engaged in production, and to foster discussion on their application to industry generally and to mass production in particular.

The cold working of metals may be said to cover processes (other than cutting) where the metal is worked, or formed at normal atmospheric temperature. The degree of cold working permissible being dependent upon the nature of the work and the malleability, or ductility, of the metal.

The processes under examination to-night are Drawing, Rolling and Raising.

Drawing.

Cold drawing may be employed to :—

(*a*) Secure accuracy of size ; (*b*) Obtain a smooth even surface ; (*c*) Produce thin complicated section ; (*d*) Affect the physical properties.

Essentially the first operation is to remove the scale formed by oxidation after hot rolling. This is done by pickling in a bath of dilute hydrocloric or sulphuric acid, afterwards swilling in water and then in a lime bath to neutralise any remaining acid. The end of the bar is then tagged to allow it to pass through the die, either in an Oliver Stamp, or skimmed in a special lathe. This end is gripped in a trolley-vice which is drawn by an endless chain. In the case of wire the bulky bench is replaced by a coiling drum. After drawing the bars are reeled for straightening. The actual flow of metal can be followed by examining the section of a die. The reaction of the die against the pull of the machine acts perpendicularly to the throat face of the die. This causes a local collapse of the metal with the result that the middle portion moves slightly in advance of that near the skin. This is more noticeable in hard steels than in soft materials, but can be lessened by reducing the amount of draft and reversing the direction of pass.

Research into the problems of drawing does not seem to have had the attention it deserves. I understand, however, that a research programme is now in hand at the Sheffield University. In the meantime a few extracts from the report on investigations by Messrs. Siebel and Pomp may be interesting. These experiments were

carried out at Düsseldorf on a specially designed machine. Arrangements were made for measuring pressures by supporting the thrust of the die on a piston connected by fluid to a manometer. Time does not permit a too detailed extract, but the slide shows a table giving comparision between angles of throat, also between various forms of lubricants.

Cold Rolling.

The objects of cold rolling may be said to be almost identical with those of drawing, namely :—

(*a*) to secure accuracy of size ; (*b*) to provide a smooth even surface ; (*c*) to affect the physical properties.

With regard to (*a*) when I say that it is possible to roll steel to a thickness of .0015 inch, it will be realised that the possible limits of accuracy are very near. Speaking of (*b*) the next slide—a micro photograph—will show a comparison between a machined, a ground and a rolled surface, all magnified 100 times. Perhaps the most important point is the effect of cold rolling on the physical properties of the material. In hot rolling the ingot or billet leaves the furnace at a temperature of about 1,000°C. well above the critical temperature. During rolling, this temperature falls (particularly is this the case with thinner gauges) until toward the end the temperature may quite conceivably fall below the critical point. Where steel is rolled with a view to giving a good surface this is definitely the case.

Re-crystalisation takes place at the critical temperature so that any distortion that may take place below the critical point remains permanent. In other words, the steel becomes slightly work hardened. Any variation in the temperature means a variation in the soft quality of the steel. Close annealing of the material in this condition would tend to produce a coarse weak structure which is of little use for deep drawing work. There has been a great deal of experimental work done in this connection, with the result that normalising has been introduced in certain sheet mills. The amount of cold work involved, in cold rolling, obviates this trouble to a very great extent providing that the annealing temperature is carefully controlled in relation to the amount of cold work the material has received.

There have been many developments in the art of pickling for cold rolling during recent years, and I will trace briefly the processes involved. For pickling, hydrocloric acid is preferred to sulphuric as it is less likely to pit the steel and is far less unpleasant to the operator. The old type wooden vat has been replaced by brick built containers, lined with a special acid resisting brick, the whole vat being floated in the joints with a bitumen solution. For the purpose of speeding up the operation the acid is heated by steam jets, or by immersion heaters. An interesting theory is advanced to explain

the process of pickling. It is claimed that since strong acid will not attack metals the same way as weak acid ; and further, that no acid will attack a chemically pure metal, that the action of an acid on a metal is electrolytic due to a difference of potential between the impurities. This action is made possible by the dilute acid in the same way as wireless accumulators operate. In the process the liquid is split up ; hydrogen is given off which lifts the particles of scale, these particles then fall to the bottom of the vat. If the basic metal were chemically pure the acids would not attack them, but since this is not the case, care must be exercised, otherwise pitting of the surface will take place.

In strip rolling de-scaling is often introduced to expedite the process. This is a simple operation which by passing the strip over and under corrugated rolls leaves a series of small kinks, thus flaking off the strip. After liming and washing out, the material passes forward to the rolls. Here it is reduced in thickness from 40 to 60 per cent. according to the gauge and grade of the material. The finish is obtained by a combination of pressure and slip. If we examine the conditions operating within the arc of contact we find that whilst there is one point at which the material is travelling at the same speed as the rolls there is relative movement over the rest of the surface. This gives a burnishing effect which, provided that the rolls are in good condition, combined with the enormous pressure on the material, produces the familiar bright clear surface.

Design of Rolls.

There is a great difference of opinion as to the merits of different kinds of rolls. They comprise two high, three high, four high and cluster. It is claimed, with some basis of truth, that the smaller the arc of contact the greater reduction per horse power, with less work hardening effect. To reduce arc of contact one must reduce the diameter of the roll. This means weakening its resistance to bending and involves, therefore, some form of bolster. Backing rolls are provided for this purpose. The three high mill is, at the best, a compromise, and its only virtue is that of low first cost. Since one side of the strip only is reduced by the small roll, the pressure being equal on both sides will result in one side having a greater reduction than the other. In the four-high, whilst we have small working rolls well supported on the vertical axis, the tendency is for the rolls to squeeze out of the vertical line, thus creating a horizontal bending movement on the rolls, which tends to affect the accuracy of the strip. The cluster mill, it is claimed, overcomes this difficulty, but since, for reasons of simplicity, the force must be applied vertically and the resultant force is at an angle to the vertical, then for a given load a heavier screw pressure is necessary.

One of the most striking features about modern roll design has

been the development in roll bearings, which has had a revolutionary effect on rolling speeds. The slide shows an old type of neck bearing which was lubricated by a combination of water and suet, the water for the purpose of keeping the neck cool, and the heat of the neck being relied upon to melt the suet before lubrication became effective. Two firms in particular have concentrated on this question with the result that rolling speeds have been increased from 40 to 200 f.p.m. The principle of flood lubrication bearings is that of a constant flow of oil into a well surrounding the neck and actual bearing surface. The effect of the high running speed is to induce oil between the neck and the bearing surface, thus ensuring a perfect separation. One distinct advantage of this type of bearing is that it can be used on two-high roll sets. The Skefko Roll Bearing is the second serious attempt at this problem of reduction of roll friction. The standard machine is of necessity a multi-roll mill, but an ingenious device has been introduced to permit the application of anti-frictional bearings to old type mills. This is accomplished by introducing a large circular ring embracing two outer rolls which have small roller bearings to preserve alignment. These rings are free to rotate and actually take the form of an outer race ; the large rolls act as rollers and the small roll as the inner race. Pressure is applied by pushing these outer rings off centre, thus reducing the distance between the rolls. The disadvantage of this machine is that the actual range of work is limited.

Heat Treatment.

Mild steel strip which has been rolled, if examined under the microscope will show an elongated structure which creates what may be termed "work hardness," so much so that a material giving a tensile strength of 24-26 tons in the annealed condition, will give 36-40 tons after rolling, with an elongation as low as 6 per cent., whilst a carbon steel giving a normal tensile of 36 tons may be pushed up to give 70 or even 100 tons per square inch. For a soft steel, therefore, some form of heat treatment becomes necessary—that in most general use being Bright annealing. For this purpose, the steel is packed in steel pots, or coffins ; air is excluded by filling all spaces with cast iron borings. The pots are then charged into a furnace and soaked for a period of 24 hours. On withdrawal, a current of coal gas is passed through to prevent any possibility of air being drawn into the pot during cooling process. The material is then inspected, oiled, ready for despatch.

A word about normalising is not out of place at this point. The difficulty from the point of view of a bright steel is that any attempt at normalising involves discolouration of the material, since normalising means a quick cooling through the critical range, and the cost of doing this in an inert atmosphere is prohibitive.

Cold Raising.

The cold raising of metals is a fascinating study and is perhaps one of the most ancient of the crafts of metal working. It is not the intention of the speaker to go into the question of tool manufacture and design, since there are many of our members who are better qualified for that privilege. Dealing with the processes in their historical order, one must mention hand raising, which unfortunately from one point of view, is becoming a lost art in the face of machine competition, so much so that I am afraid many of the artistic mementoes purchased from the East saw the first light of day in a Birmingham press shop. I do not want, however, to mention hand raising from the point of view of the method by which means the metal is forced to flow. If you attempted to form a cup by giving it a blow in the centre you would merely produce a depression with a series of wrinkles on the outside. In all deep raising work there must be a change of position between the crystals of the material. This flow must be encouraged, otherwise the metal will take the line of least resistance and pucker. In the case of hand raising this is done by working the material from the outer edge towards the centre, gradually deepening the pressing until the desired shape has been formed.

The next process is that of spinning. Here again we work the material from the outside. In the case of parallel work : A chuck is screwed on the nose of a high speed lathe almost identical with the ordinary pattern maker's lathe, with the exception that the hand rest is drilled to take vertical pegs which take the thrust of the spinning tool. These tools are about 15 inches long, of varying forms to suit the particular class of work and have long wooden handles which are held under the arm of the operator. Using the tool rest as fulcrum the material is gradually worked down on to the chuck by rubbing backwards and forwards across the full face of the blank. In the case of curved articles these may be :—

(*a*) Spun in the air ; (*b*) Spun on section chuck ; (*c*) By means of inside or outside rollers.

When the variation in diameter is excessive as in the case of the Jardiniere, a cup shaped blank is first formed halfway between the maximum and minimum diameter, and one part is pulled out against an external roller, the remainder being pushed in against an internal roller. Whilst dealing with the question of spinning, it might be worth while mentioning a process now in operation in Germany. To overcome the work-hardening effect of spinning, a series of Gas burners are located around the work and the whole process carried out at a red heat. In this way welded steel cylinders are spun down into milk churns at one operation, thus making an enormous saving both in material and labour.

Stamping.

In the stamping process the material is worked in the centre, the puckers being allowed to form and being periodically hammered out. In a typical stamping job the die is filled up with sand to a level which controls the depth to which a stamping may be safely taken without fear of the flange being too badly wrinkled. The hammer is then lowered down into position ; a clay dam is formed and lead poured into the mould thus produced. The hammer is lifted, sand removed from the die, and after a few sharp blows to bed the "force" to the die, we are ready for the first operation.

The sheets after circling or shaping, are placed on the die, two or three at a time according to their thickness, and lightly pushed into the die, after which a few sharp blows are given to stamp out the puckers. The batch having been completed, the "force" is melted down, re-cast a little deeper, and again put through, this process being repeated until the finished depth has been reached. Obviously, with this method, due to the repeated hammering of the edges, work hardening will be accelerated, and it may be necessary to anneal two or three times if there is any depth required. The inherent advantage of this process is that relatively small quantities of fairly complicated shapes may be produced economically, since the die cost is small.

Double Action Press-work.

In the double action press the two principles previously mentioned are combined. The tools are comprised of a punch, pressure plate and die. The punch takes the place of the force in the stamping operation ; the pressure plate combined with the die work the outer edges of the material and force it to flow without puckers. In this way, we combine the processes previously mentioned with a great saving in labour costs, although the tool costs are higher. There are one or two points worthy of consideration in double action press-work. We have first of all the resistance of this material against ow which increases as the cup assumes shape. In addition we have the friction between the pressure plate and the blank, and between the blank and the die. There must, therefore, be a definite limit to the amount of reduction that can be made at one operation. In the succeeding operations we have further complications. Whilst the material forming the sides of the cup have been work hardened, and therefore increased in strength, which means increased resistance to change of shape, the area under the punch is very little stronger. Obviously then, the second operation cannot be so severe as the first. Another factor is that whilst the material in the first operation turns one corner, that in the succeeding operation turns two. In thick material we also have this condition operating. The inside of the cup is being pushed into a smaller space than the outside. This

may be balanced somewhat where the shape of the article permits, by an inside out operation, in which the material is turned completely inside-out.

Blank Forms.

Dealing with blank forms, it is often said that the life of adraughtsman is made up of straight strokes and circles. If we apply this principle to the development of blank forms we shall not go very far wrong. It is a fairly simple matter to find the blank for a cylindrical pressing from the sum of the area, of the side and the bottom. If we split up the pressing into straight lines and curves we can draw the development of the straight sides, work out a blank radius for the cup at the corners and draw this in. There is, however, one important point and that is the distinct cleavage between an ordinary bending operation represented by the flat side and the metal which flows represented by the corners. There must be an easing off between these two points, otherwise breakage will occur. Oval shaped pressings may be treated in the same way.

Subsequent Heat Treatment.

The heat treatment of steel, particularly for this type of work, calls for a certain amount of care, because the necessary treatment depends very largely on the work—the physical work—that the material has had. If you attempt to close anneal a steel which has not been cold worked, you will get what we call " grain." This coarse structure is not unfortunately revealed by the ordinary hardness testing and would probably show extreme softness under either Brinnell or Scleroscope or similar hardness tests, yet in use would shew Orange Peel surface or even break due to extreme weakness.

If we examine a pressing which has had one or more cupping operations performed upon it we shall find that whilst the sides have been work hardened (and are therefore in a condition to benefit by Heat Treatment) the bottom is almost in the original soft condition. Close annealing would therefore tend to produce a coarse structure in the centre and a fine structure in the sides. The only safe treatment under these conditions is to Normalise.

There are many systems of testing materials. We have amongst others the scleroscope, the Brinnell, the Rockwell, the Ericson and the Avery. To my mind, only the Ericson and the Avery tests are of any use to indicate the suitability, or otherwise, of material for use in drawing work. In cold work you get de-formation of the crystals, that is to say, the crystals move over in relation to each other. The only sound test then for testing the material is one that approximates in some way the actual operation of the job for which that material is needed, and this the Ericson and the Avery tests do to a very large extent.

With the ordinary hardness testing devices at present available, not only do they fail to indicate the grain structure of the material, but when dealing with very thin soft material, the tendency is for the anvil effect to complicate the reading. That is to say, the testing medium, be it hammer or ball, penetrates the material and gives an average of the anvil and material.

In conclusion, Mr. Berry said he felt that his paper had been sketchy and must advance as his excuse the breadth of the subject, and that he had aimed at a review of the whole rather than a detailed account of any one branch. He also acknowledged the assistance of Messrs. Rhodes of Wakefield, Incandescent Heat Co., W. H. A. Robertsons of Bedford, Skefko of Luton and Stourbridge Rolling Mills Ltd., who had loaned slides.

Discussion.

Mr. Groocock, President, Birmingham Section: I am sure you will agree with me that we have been listening to-night to a lecture that has been extremely interesting, and one that has also been very useful to us. As production engineers we have one main function—to keep on producing cheaper articles and still cheaper articles. Now if we watch the tendency of latter day methods we shall find that they are working in two directions. On the one side we are able to build up articles by welding, on the other side we are having a combination of a solid material and a pressing and thus we are saving material. The tendency is to save both labour and material, but we have been very wasteful on the material side, I think, and now we are swinging round in the other direction and shall do more in the future to use both cold and hot pressings in our designs. I do not propose to ask many questions at this stage, but there are a few points specially that interested me—one was the question of the rolls. I understood from Mr. Berry that these are of nickel chrome. I would just like to ask him whether they are heat treated in any way, and if that heat treatment takes place between the preliminary grind and the finished grind, or where the heat treatment does take place. There is another point that struck me when I saw the slides, and that was the particularly long furnace with the travelling beds on which was mounted trucks. I wondered whether they had introduced hydrogen into this annealing as they do for some of the material used on electrical machinery. Yet another point was the way of making lead forces. I would be glad if Mr. Berry would tell us something of the material, or whether it is plain lead, or lead and tin, and in what proportion. It seems to me that lead itself would be too soft, and that too much tin would cause flaking. The last remark that I have to make is with regard to the scleroscope. I am not quite sure that Mr. Berry is right when he said the scleroscope on thin material would probably measure in part the hardness of the anvil. I think the probabilities are that in the case of very thin material, what the scleroscope does measure is the spring of the material itself rather that its hardness, because it is almost impossible to hold the thin material down on to the anvil, and consequently you are not dealing with the solid.

Mr. Russell: Mr. Berry said that he tried to get some information on wire drawing. What he said is perfectly true—there is no information on wire drawing. In my opinion, wire drawing is one of those trades which has not advanced as others have. To-day we are still in the hands of the drawer; the man who has been drawing all his life. Quite often in one shop we get men with various opinions. Mr. Berry mentioned some lubrication which, in my opinion did not altogether cover the ground. For rod drawing we prefer to use soap

and water. The statement about paraffin is open to doubt. We do not find it so, but there was no mention of dry lubrication. A number of dry lubricants are used to-day, such as soap, flour and lime, and act merely as lubricants. There is another—copper sulphate, where you put a coating of copper on your bar and draw your die over it. To-day we have specification calling for hardnesses—very high hardness—very bright surfaces, and also fineness of gauge. A 6° die would not get you very far ; 28° or 30°, that is 15° from the centre, is a very useful angle to use with wire drawing, or in rod drawing for that matter. So far as the rolling is concerned, I think the question of four-rolls and cluster rolls is still open to discussion. We still have men who believe that the old-fashioned two-high is the best. In South Wales they are of the opinion that they are getting better results by putting sheets through singly at a high temperature. So far as testing of sheets is concerned, I am entirely in agreement with Mr. Berry—the only real test is the cupping die which he has explained. Unfortunately, we do get customers who stipulate scleroscope tests, and we are very often forced to give them something that we do not quite agree is the best material.

Mr. White said that when Mr. Berry put up the first slide he outlined the size of the arc of contact, and he said when you have a large roll diameter, you have a larger arc of contact and, of course, greater horse power. That point was not quite clear to him. It seemed to him that if the same reduction was made on the metal, the same amount of work was done. He thought that the larger the contact, the more energy would be absorbed. If that were the case, it would seem that better burnished effects would be obtained on the large roller. He would like Mr. Berry to enlarge on that point. He would like to know what type of welding was used in the case of the milk churns mentioned, also how the gas burners were arranged.

Mr. Leedham-Green : I think one of the greatest handicaps under which we—and I speak as a steel-roller—are labouring at the moment, is a lack of co-operation between the rollers on the one hand, and the buyers and production engineers on the other. More and more manufacturers are finding that they can save in the cost of their raw material by using steel strip in place of non-ferrous metals. Occasionally, however, they find they encounter difficulties which they had not previously experienced, and are immediately discouraged. These difficulties and failures frequently arise because the buyer fails to convey to the roller a clear idea of the article or stamping he proposes to make. Generally speaking, it may be said that with the exception of faults inherent in the steel itself, such as laminations, blow-holes, rokes, etc., the majority of failures are due to the grain size of the material. Moreover, in my experience, I do not consider that there is a standard grain size which is suitable for

all pressings. It is true that a steel with a very small grain size will, if it does not fracture, at least exhibit a quality of " toughness " which is extremely damaging to the dies, and on that score alone is undesirable; that an exaggerated grain size will give rise to " Stead's brittleness," and that, therefore, a medium sized grain is suitable in probably 85 times out of 100.

There are, however, cases when the pressing demands a steel of a particular grain size. In this connection I have examined the behaviour of steels of different grain size with, in many cases, very interesting and curious results. Thus, a motor-cycle hub which had fractured in service proved to have the same grain size as a steel which has been found to be the most satisfactory in a different type of pressing. The grain size was large, and in the case of the hub, which was subjected to intermittent stresses at about 45° to the direction of rolling, gave rise to " Stead's brittleness " (to which I have already referred). In the case of the other pressing which had to bear no such stresses, and only required to be pressed into an ornamental shape, it was found to cure troubles which had previously been encountered in steels of a smaller grain size. Again, I have found that an alteration in the average grain size of only 3/1000ths of a millimetre has caused the formation, or disappearance of " stretcher strains," a phenomenon very frequently encountered in shallow pressings where the amount of the draw is comparatively light. The study of stretcher strains is incidentally a very interesting subject. They are caused by a different resistance to " slip," with the result that the " slipping " or " gliding " action of each grain as it responds to the elongation of the draw does not take place simultaneously. The yield point of some of the grains is passed in the drawing operation, thereby forming a slip band, which in turn causes a group of grains to yield, and results in a " stretcher strain," whilst the remaining grains return to their original shape. If, of course, the draw is sufficiently deep, the elastic limit of all the grains is passed and the surface remains smooth.

Manufacturers who have not previously encountered this phenomenon with non-ferrous metals, because such metals have no definite " yield " point, may well think that steel is not suitable for the job. But in this case, as in so many others, a little co-operation, a very slight alteration in the rolling processes, and where necessary, a little research, will eliminate such troubles. If production engineers only consider for a moment the manifold processes through which a cast of steel is put before it reaches the press shop in the form of deep stamping strip, I think they will sympathise with the steel rollers in their task of satisfying their more and more exacting demands, and I appeal to them to co-operate with the rollers to the end that these demands may be satisfied by 100 per cent. perfect material.

MR. WRIGHT said he would like to ask Mr. Berry if the Herbert Pendulum test had ever been tried. Mr. Berry also mentioned machine tools and the operations to be divided into cutting and non-cutting, and dealing with the non-cutting, there is an example of cold working in very large shafts, that is, the finish of railway axle journals. The loads on the journals are very heavy, and lubrication is not any more than it ought to be and still they run remarkably well, and this rather supported a strong opinion of his, that ordinary grinding used for the finish of journal bearings is not good enough ; it does not produce a good enough surface for a heavily loaded journal bearing, and he was quite expecting at any time that some improved method would come into use. He said that Mr. Berry's remarks about the lubrication of rolling mill bearings gave him an opportunity to say that on rolling mills, the bearings are always the limiting feature. Anyone interested in the question of roller bearings would be pleased, he thought, to communicate with the Skefko Company, who make a lot of experiments on the pressure required on different sizes of rolls and so on, and have some very interesting literature on that subject which no doubt they would be pleased to supply.

MR. WALMSLEY said he came as a visitor, but it seemed to him that he was in the position of a supplier rather than a consumer. Two gentlemen had mentioned that if the consumer would get more in touch with the supplier they would probably get more out of him. It had always been his object to endeavour to let the man know his troubles. There had been some reference made with regard to the scleroscope, and the Ericson for testing, but he felt that you cannot condemn either principle in the examination of material. In the case of soft materials, no doubt the Ericson is a very good instrument up to certain thicknesses of material. If you get down to very hard materials you cannot specify the Ericson by any means, you have to use the scleroscope. There was another point Mr. Walmsley mentioned, and that was stretcher marks in steel. He stated that stretcher marks were a great cause of trouble. He also knew that the very small grain size that is aimed at is not always the best. On the other hand, if a good finish on the job was aimed at, the grain size could not be considered negligible. Taking another case of brasses, he had found round about a gauge of 1/32 inch thick, a range on the Ericson can be got from about 9.5 m/m. to 11.5 m/m., that is a 2 m/m. range. He said there are very few metal people who will even supply a specification and he had found no drawing to arrive at a specification. What is wanted is something between 10 and 10.5. It is extremely difficult to get within a limit of that sort.

MR. HANNAY said there was no doubt that in the next few years this working of metals is going to play a very large part in production engineering. He had hoped that Mr. Berry was going to touch on some-

thing more than just the usual steel working, because production engineers are very anxious to have other materials, bars, etc., that can be worked in various ways, because it is known that if they can work materials cold the saving is enormous. When he was in the United States to see what was being done in various factories, he made a note of this and found that the steel makers had an army of men there, running backwards and forwards between the rolling mills and the factory. The mills did not seem to be able to keep one supplied regularly with the same grade of material. He did not know whether it was the steel maker or the roller who was to blame, but users were certainly handicapped because of the irregularity of of the material supplied.

MR. YOUNGASH said he thought that the problem of lubrication was in a way very much the same as the problem of carrying the heat away from the cutting tool. We are apt to look upon that as a question of lubrication. It is a matter of dissipating heat, and he suggested that what is needed for that purpose is an oil which has particularly good properties in the matter of carrying heat away. With regard to the Brinnel testing, Mr. Youngash thought this is a very interesting question, because placed in the same way to ordinary machining operations, the scleroscope is usually for dealing with harder conditions than the Brinnel. Pieces that are really suitable for the scleroscope are too hard for usual machining methods. The Brinnel does not indicate the condition of the metal, that is to say, the piece of metal is heat treated and you can depend on its tensile strength, but you cannot depend on its impact. One of the things that struck him most was that it seems very curious that there is practically no difference in the width of the face when it has been rolled. The grains are presumably elongated, but it seems extremely difficult to say why they do not widen at the same time to some very definite proportion. He would have thought they would. Another point that he was interested in was the question of the amount of power required for these operations, and how they would compare with machine operations of the ordinary sort, that is to say, for a given reduction in diameter the amount of power required to affect that result would probably be very much more with a roll or a drawing operation, than it would be with a cutting operation. What would be the proportion. Is there any sort of rule, or can we get any idea of it ?

MR. BERRY, replying to the various speakers, said : With regard to treatment of rolls, these are ground and polished after hardening. In connection with heat treatment, I think this question is more or less controlled by the routine and size of the product. It is a very expensive matter to fill a huge furnace that is required for continuous heat treatment of sheets with gas like hydrogen. It is quite true that to some extent there is a tendency in this direction, but as yet, so

far as my knowledge goes, there is not a successful, or shall we say a commercial bright heat treatment furnace using an inert gas. The third item with regard to lead forces; actually a metal called "Regulus" is included with the lead to harden it. It is a proprietary metal which I believe contains antimony, but I will, if Mr. Groocock wishes, get the name of the suppliers and let him have it.

With regard to impact hardness testing, this point seems to be exercising many minds and perhaps if I relate a recent experience, my rather strong views on this question may be explained.

Quite recently my firm were asked to send some soft material abroad and were given a hardness number to work to. The question was raised with the Agent who was informed that in our opinion the Ericson would be the better test, but we would make all efforts to ensure that the material confirmed to the hardness number specified.

A local Research Laboratory were approached and asked to give us the ratio between our own form of test and that required by the customer. We were told that there was no reliable ratio, and at our expense, a series of tests were carried out which revealed the fact that on very thin material a higher (i.e. harder) number was obtained for the soft material than for the hard. In reply to Mr. Russell, I am very much obliged to him for his suggestions on the question of Lubrication. Incidentally, Sedel-Pomp do mention Soap-stone mixed with rape seed oil as giving the best results.

With regard to annealing, it is quite true that single sheet annealing is being done, but where this is the case, a supplementary pickling operation is necessary to remove the scaling effect.

Mr. White raised the question of roll diameter as affecting power. At first, when this question was put up to me some months ago, I did not think that the change in roll diameter should seriously affect the power, but subsequent tests have proved this to be the case. You do definitely get a better finish from a big roll than from a small one. If you compare the process with that of planishing a sheet with a hand hammer the comparison becomes clear. With a small faced hammer you get greater penetration, whilst with a broad faced hammer you obtain a better surface with less reduction of thickness.

In reply to the next question, the welding was oxy-acetylene, and the gas burners are fixed; they do not revolve with the job. They are a fixture, but so arranged that they can be closed down as the diameter of the article is reduced so that the flame is always on the job itself.

Stainless steel. This is now produced, of course, in drawing quality, but its nature is such that it work hardens very quickly and the annealing is a problem. I believe Messrs. Firth recommend a temperature of 1150° C., but give this figure with reservation. If you have difficulty there I would much rather yougo direct to the makers.

Replying to Mr. Green, particularly with regard to grain growth, I would say that was why I made a particular point at the end of my talk of mentioning heat treatment.

I had a very peculiar experience a few weeks ago with material which was supplied to Ericson test. The material stood up to the work perfectly. There was not a sign of a crack on the job. A few weeks after delivery we had an S.O.S. from the firm who bought the material. On inspecting, my first thought was that it was on some job where vibration was severe and was causing crystal growth.

Further investigation revealed the fact that subsequent stoving after enamelling was responsible for the brittleness. These fittings were then normalised previous to enamelling and the trouble entirely eliminated. Only a few days ago, in a local garage, I saw the front engine stay which had been cold pressed and stove enamelled which had fractured in a similar manner, and was told it was a common fault with this type of car. Here again, a normalising process after cold working would cure the trouble.

With regard to stretcher strains, there you touch upon a very sore point, and although I have heard many explanations of its causes, I have yet to find the man who can specify a cure.

The suppliers of steel could do better if they knew the actual requirements of the job. There have been jobs where a medium hard, or half hard, or medium soft, will do the job better than a dead soft steel, and if we did have more co-operation between the supplier and the user, I think we should get to a solution of our problems much more quickly.

Mr. Walmsley raised this point, also the question of scleroscope. It is perfectly true that the Ericson is not useful for material much above $\frac{1}{8}$ inch thick. As a matter of fact we have considered putting down some small press to test our material actually on double action conditions so that we could cover the full range. I am not condemning the scleroscope, or the Brinnel, or any form of test in their own particular sphere, but they should be confined to the job for which they are most useful, and we should, to my mind, get to some definite standard, and it should be a standard understood both by the user and the supplier ; some standard for measuring the deep drawing qualities of the steel.

Answering Mr. Wright, I have not tried the Herbert Pendulum test. But even the Herbert Pendulum has its limits. No test of that type, to my mind, will give you any indication of the grain condition of the material, and it is this grain condition that is going to make, or break that material for deep drawing or cold working.

With regard to Mr. Hannay's statement, I have been on both sides of this problem ; I have been in the position where I always blamed the steel maker and was not interested in the steel problems myself, and I am now in the position where it would be most con-

venient to blame the tool makers, but do not. I think we should understand that there is a great deal of difference between a straight cutting or forming operation, and the manufacture of steel; the chemical processes involved; the difficulty of control; of seeing what is inside the steel, and what is happening during those vital moments of production. Another speaker has mentioned that steel makers now try to get all the defects in the inside of the steel instead of having the blow holes on the surface. The tendency now is to concentrate these defects in the centre of the billet. Unfortunately that leads us into another trouble, which we call Lamination. If the faults are concentrated on a point they tend to become aggravated, and we then meet the question of lamination.

I am glad Mr. Youngash raised this question of machine tools, because I think it should be realised that there is development taking place in all directions. To my mind we are too inclined to cry "stinking fish" in this country. It is a far better sales cry to say that we are progressing than to say that we are down in the dumps. His point of increase in width. The best analogy I can give to illustrate this point is to be found on the pastry board at home. If you follow that homely operation you will notice that the pastry elongates in the direction of rolling. In the case of steel or materials less plastic, this tendency is more marked, and it is only when very heavy pinches are taken, that we find any tendency of the material to spread. It elongates in the direction of rolling. With regard to the point that the cutting tool is very similar to rolling, I do not quite agree with him, because in rolling you are definitely rubbing. With cutting you have a pure shearing action. Your tendency is to eliminate rubbing, that is why you use a sharp edged tool instead of a round edged tool. I cannot give Mr. Youngash at the moment, any relation between power for reducing the thickness of the material and the power for removing metal, but I should say definitely that the power for rolling would be very much more than that required for cutting.

A vote of thanks to Mr. Berry concluded the meeting.